Mass balance models of the eastern Scotian Shelf before and after the cod collapse and other ecosystem changes

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ABSTRACT

Bundy, A. 2004. Mass balance models of the eastern Scotian Shelf before and after the cod collapse and other ecosystem changes. Can. Tech. Rep. Fish. Aquat. Sci.

This report is one of a series from the DFO project, Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic (CDEENA). It documents the input data, the development and balancing of two detailed Ecopath mass balance models of the eastern Scotian Shelf, Nova Scotia for 1980-1985 and 1995-2000. The models were developed to explore how the ecosystem has changed, in terms of its structure, function and the role of key species. The two time periods, 1980-1985 and 1995-2000 represent the eastern Scotian Shelf before and after the collapse of cod and other groundfish. Information on biomass, consumption, production and diet of major species or species groups is described. For the first time, an analysis of uncertainty was conducted to examine the effects of the uncertainty on model estimates. A comparison of the two Ecopath models demonstrates that though total productivity and total biomass of the ecosystem remains similar, there have been changes in predator structure, trophic structure and flow. The ecosystem has changed from a demersal dominated system to a pelagic dominated system. With the exception of the average trophic level of the catch, there is no effect of the groundfish collapse on the emergent properties of the ecosystem. The eastern Scotian Shelf ecosystem is profoundly altered and it exhibits a classic case of "fishing down the foodweb", although system properties are generally conserved.

RÉSUMÉ

Bundy, A. 2004. Mass balance models of the eastern Scotian Shelf before and after the cod collapse and other ecosystem changes. Can. Tech. Rep. Fish. Aquat. Sci. 2520

Le présent rapport s'inscrit dans une série de textes présentés dans le cadre du projet du MPO appelé Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic (CDEENA). Il documente les intrants, l'élaboration et l'équilibrage de deux modèles détaillés de bilan de masse (Ecopath) de l'est du plateau néo-écossais de 1980 à 1985 et de 1995 à 2000. Ces modèles ont été élaborés pour étudier l'évolution de la structure et de la fonction de l'écosystème ainsi que du rôle qu'y jouent certaines grandes espèces. Les deux périodes considérées, soit 1980-1985 et 1995-2000, correspondent à ce qu'était le plateau néo-écossais avant et après l'effondrement des stocks de morue et d'autres poissons de fond. Dans ce rapport, on présente de l'information sur la biomasse, la consommation, la production et l'alimentation des principales espèces ou des grands groupes d'espèces. Pour la première fois, on a procédé à une analyse de l'incertitude et examiné les effets de cette incertitude sur les estimations découlant des modèles. Il ressort d'une comparaison des deux modèles Ecopath que, bien que la productivité et la biomasse totales de l'écosystème restent similaires, des changements sont survenus dans la structure des prédateurs, ainsi que dans la structure et le flux trophique. L'écosystème a changé; autrefois dominé par les espèces démersales, il est maintenant dominé par les espèces pélagiques. Sauf pour ce qui est du niveau trophique moyen des prises, l'effondrement des stocks de poisson de fond n'a pas eu d'effet sur les propriétés émergentes de l'écosystème. L'écosystème de l'est du

plateau néo-écossais est profondément modifié et il présente un cas classique d'épuisement successif, de haut en bas, des niveaux trophiques par la pêche, quoiqu'il conserve généralement ses propriétés.

INTRODUCTION

The eastern Scotian Shelf has undergone considerable change over the last two decades. In the early to mid-1980s, there were substantial groundfish fisheries: in the early 1990s, the groundfish fisheries collapsed. Concurrent with these changes have been an exponential increase in the grey seal population, and large increases in small pelagic species such as sand lance and herring and invertebrates such as shrimp and snow crab. Meanwhile, environmental changes such as cooling of the shelf waters may have reduced productivity of species, changed their distribution patterns or reduced survival. In 2003, the cod stock in the eastern Scotian Shelf has not recovered, and the haddock stock has recovered numerically, but with an altered, reduced growth rate.

This situation is not unique to the eastern Scotian Shelf. In order to explore what may be causing these changes in the marine ecosystems of Eastern Canada, and why cod stocks have failed to recover, a multispecies, ecosystem approach is required. In 1999 the Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic (CDEENA) project was funded by the DFO Strategic Science Fund to address the question "What have been the relative effects of environmental variation, predation and fishing, and their interactions, on the population dynamics of marine finfish and shellfish inhabiting shelf ecosystems of the Northwest Atlantic?

The 3 main objectives of CDEENA were to:

1. to model the structure and function of the shelf ecosystems of eastern Canada and to determine how the physical and biological components of these ecosystems change over time and space,
2. to fill critical gaps in the knowledge required to develop model descriptions of these ecosystems,
3. to use these models to investigate hypotheses concerning the impact of changes in reproductive potential, mortality, and trophic interactions on the dynamics of Atlantic cod and other groundfish.

In order to meet these objectives, mass balance ecosystem models were developed for each of the systems (Newfoundland Labrador Shelf, Northern and Southern Gulf of St. Lawrence and the eastern Scotian Shelf) before and after the collapse of groundfish and other ecosystem changes. This report documents the development of mass balance models for the eastern Scotian Shelf before and after the groundfish collapse of 1993.

THE EASTERN SCOTIAN SHELF

Delineating ecosystems is always problematic: the ecosystems of the polychaete worm, cod and cetaceans overlap, but they are not the same. Species inhabit different spatial scales, habitat topography varies spatially and environmental influences and currents have spatially differentially effects. However, for the purposes of model building and ecosystem management, some criteria have to be used to define an ecosystem. In the case of the eastern Scotian Shelf, there were several key features that should be captured, such as the dynamics of cod, haddock, grey seals, shrimp, sand lance and herring. With the exception of grey seals, the distribution of these species is largely contained by NAFO Divisions

4VsW (Figure 1), and this area was chosen to delimit the model, up to a depth of 500 m on the southern edge of the Shelf. Species that are not contained within the model area, for example migratory species such as cetaceans or tunas, are included in the model, but their annual biomass is pro-rated for the amount of time spent in the model area. Several recent publications (DFO (2000a), Breeze et al. (2002), Zwanenburg et al. (2002), DFO (2003)) review the physical and biological features of the eastern Scotian Shelf.

METHODS

Ecopath is by necessity a simplified approach to ecosystem modelling. It encapsulates the whole biological system, but species are aggregated into functional groups in order to make the model tractable. Each group is represented by two linear equations, each of which must balance.

The first equation ensures balance between groups in the model

(1) $P_i = Y_i + B_i * (M2_i + E_i + MO_i + BA_i)$

Where, for group (i),

P_i = the annual production,
Y_i = annual catch,
B_i = the annual biomass,
$M2_i$ = total predation rate for group i,
$E\ i$ = the net migration rate (emigration – immigration),
$BA\ i$ = is the biomass accumulation rate,
$M0_i = Pi \cdot (1\text{-}EEi)$ is the 'other mortality' rate and EE_i = ecotrophic efficiency

Equation (1) can also be expressed as:

(2) $$B_i \cdot (P/B)_i \cdot EE_i - \sum_{j=1}^{n} B_j \cdot (Q/B)_j \cdot DC_{ji} - Y_i - B_i * E_i - B_i * BA_i = 0$$

Where P/B_i is the production to biomass ratio, Q/B_i is the consumption to biomass ratio and DC_{ji} is the fraction of the prey (i) in the diet of predator (j) (Christensen and Pauly 1992).

The second equation, which balances the flows within each group is:

Consumption = production + respiration + unassimilated food

(3) $Q_i = P_i + R_i + (1\text{-}GS_i) * Q_i$

Where, for group (i),

Q_i = consumption,
R_i = respiration and
GS_i = proportion of food that is not assimilated.

Other Mortality

M0, other mortality, is expressed in Ecopath as $1\text{-}EE_i$ where EE_i is the "ecotrophic efficiency". In these terms $1\text{-}EE_i$ is the proportion of P_i that is not consumed by predators included in the model, nor caught by the fishery, nor accumulated in the system, so that,

(4) $EE_i = (M2_i + Y_i) / P_i$

Solving the Model

The ecosystem is modelled using a set of simultaneous linear equations derived from the above relationships. Equation (2) is scaled by biomass. Thus production and consumption are expressed as biomass ratios (P/B, Q/B). M0 and M2 are annual mortality rates. Each group in the model is represented by the two balanced equations and requires six input parameters. Diet composition and catch (export) must be entered and three of the other four parameters (B, P/B, Q/B, and EE) must be entered. The linear equations are solved and any missing parameters are estimated. (EE is estimated if all other parameters have been entered.) The most robust approach is to enter B, P/B and Q/B where possible and allow the model to estimate EE. This provides an immediate check for mass-balance because EE cannot be greater than 1. Sometimes it is necessary to enter EE in which case a default value of 0.95 is used (Christensen and Pauly 1992).

Analysis of Uncertainty

Mass balance models are deterministic, yet require many input parameters, some of which may be poorly known and taken from other ecosystems or Ecopath models. This introduces a high level of uncertainty to the results of the Ecopath model estimates. In Ecopath, other than a simple sensitivity analysis (see Results) there is no direct way to treat this uncertainty. There is a routine called "Ecoranger", which in theory can be used to explore the effects of uncertainty, but in practise it is cumbersome, inconsistent and very time consuming.

In order to explore the effects of uncertainty on the model results, a perturbation analysis was carried out once the Ecopath models were balanced, using the "Autobalance" routine (Kavanagh et al. 2004) and the Pedigree routine in Ecopath. The Autobalance routine was originally incorporated into Ecopath to facilatate the balancing of models but can be used to conduct a perturbation analysis. The Autobalance routine randomly selects the initial input parameters from a pre-defined range of values (using the pedigree routine, see below). Thus each run starts with a different set of conditions, and the routine searched for the combination that will produce a balanced model. A balanced model is defined as one where all groups have an ecotrophic efficiency less than 1. In this case, the target ecotrophic efficiency was set to be 0.95. The Autobalance routine was programmed to run for 10,000 runs in order to reach this target.

Unfortunately, the Autobalance routine only enables the biomass and diet parameters to be directly perturbed (ie. ,it does not allow P/B, Q/B, catch or biomass accumulation to be perturbed). This is thus not a full perturbation analysis. However, the Autobalance routine does allow P/B and Q/B to be "nudged" from their initial values during the run by pre-defined steps. In this case, P/B and Q/B were nudged in 10% steps: in practice, in some model balances P/B and Q/B were nudged and in others they are not, depending on the start conditions.

The pedigree routine assigns percent ranges of uncertainty to the biomass, P/B, Q/B, Catch and diet input estimates of model estimates (model estimates have a high range of uncertainty. With this routine, the overall pedigree of the model can be compared with other models, see Christensen et al. (2000). The pedigree ranges assigned to the two models are given in Appendix 1.

Thirty model runs were completed using the autobalance routine, perturbing the biomass and diet input parameters within a pre-defined range of uncertainty, and nudging the P/B and Q/B. The thirty solutions were then used to define 95 % confidence intervals to the model estimates, giving a good idea of the uncertainty associated with the model output. When comparing models over space and time, these confidence intervals were used to determine whether differences between models were real, or an artifact created by the uncertainty of the input parameters. This is the first time this type of analysis has been undertaken with an Ecopath model.

STRUCTURE OF MODEL

Species present on the eastern Scotian Shelf were aggregated into 39 groups as shown in Box 1. There are two marine mammal groups, 1 seabird group, 24 fish groups, 8 invertebrate groups, plus 2 zooplankton groups, phytoplankton and detritus. Clearly the emphasis is on the fish groups, for this is the focus of the modelling exercise. However, it should be noted that there is insufficient data to model the invertebrate groups in much more detail than is currently used.

Box 1. Structure of eastern Scotian Shelf model

Marine Mammals and Seabirds

1	Cetea	Ceteaceans
2	Seals	Grey Seals
3	Birds	Seabirds

Fish Groups

4	L.Cod	Large Cod > 40 cm
5	S.Cod	Small Cod ≤ 40 cm
6	L.Shak	Large Silver hake > 30 cm
7	S.Shak	Small Silver Hake ≤ 30 cm
8	Hadd	Haddock
9	A.plaice	American plaice
10	L.Hal	Large Halibut > 65 cm
11	S.Hal	Small Halibut ≤ 65 cm
12	Flats	Flounders
13	Skates	Skates
14	Dogfish	Dogfish
15	Redfish	Redfish
16	Pollock	Pollock
17	T.Mack	Transient Mackerel
18	LDPisc	Large Demersal Piscivores> 40 cm (eg. white hake, sea raven, monkfish)
19	SDPisc	Small Demersal Piscivores ≤ 40 cm
20	LDF	Large Demersal Feeders > 30 cm (eg. Eelpouts, red hake, wolffish, grenadiers)
21	SLDF	Small Large Demersal Feeders ≤ 30 cm
22	SDFs	Small Demersal Feeders (eg. Sculpins, shannies, blennies)
23	Cap	Capelin
24	Slance	Sand lance
25	T.Pels	Transient Pelagics (eg., tuna, swordfish, shark)
26	S.Pels	Small Pelagics (eg., herring, argentine)
27	Mesop	Small mesopelagics (eg., lantern fish, hatchetfish)

Invertebrates

28	Squid	
29	LCrab	Large Crabs CW > 95 mm
30	SCrab	Small Crabs CW ≤ 95 mm
31	Shrimp	Shrimp
32	Echin	Echinoderms
33	Polyc	Polychaetes
34	Moll	Bivalve Molluscs
35	OBI	Other Benthic Invertebrates
36	LZP	Large Zooplankton
37	SZP	Small zooplankton

Primary Producers

38	PHYP	Phytoplankton

Detritus

39	DET	Detritus

Some of the groups are split into large and small (cod, silver hake, halibut, demersal piscivores, large demersal feeders and crabs). These are split to model more accurately the effects of trophic ontogeny, size selection in fisheries, immature and mature fish and cannibalism.

PARAMETER ESTIMATION

Biomass

Biomass of fish species was estimated from the RV groundfish survey, adjusted for catchability. Catchability for many species was available on a length basis, based on a meta-analysis of trawl survey estimates of catchability by Harley and Myers (2001), Harley et al. (2001). For species for which length-based catchability estimates were not available, a single "bulk" catchability estimate was used for all length groups (Harley et al. 2001).

Biomass accumulation

Biomass accumulation was estimated from catchability adjusted estimates of annual biomass. If there was an increase or decrease in biomass over the time period of either model, and if this formed part of a larger trend, a regression analysis was done for those years. Biomass accumulation was estimated as the slope of the regression.

Production

Christensen et al. (2000) refer to production, in the Ecopath context, as "the elaboration of tissue (whether it survives or not) by a group over the period considered, expressed in whatever currency has been selected". Bundy et al. (2000) discussed different methods of estimating production, but in fact, Christensen et al. (2000) indicate that it should be assumed that the production over biomass ratio (P/B, which is the actual input to the model) is equivalent to total mortality, ie., Z=P/B (Allen 1971), "Even if the parameter is labeled 'production/biomass' in EwE, what should be entered is actually the mortality rate". However, it should be noted that this only holds in the case where there is no biomass accumulation, for Z=P/B only in the steady-state condition. When there is biomass accumulation, P/B is necessarily greater or less than total mortality. Thus, with this assumption, Ecopath approach remains grounded in the steady-state assumption. This should be taken into consideration for groups with a biomass accumulation term, for it is not possible to enter P/B and Z separately and thus Z will be over or underestimated.

Total mortality was estimated using catch curves and Paloheimo's method where possible. If the data was not available for these methods, the empirical relationship, P=M•B+C, where M= natural mortality, B= biomass and C= catch was used. This was then expressed as P/B. It is necessary to assume a value for natural mortality, unless it is known. Where it was not possible to estimate P/B, values from the literature were used.

Consumption

Consumption for the 1995-2000 model was estimated from stomach data collected during Research Vessel surveys of the eastern Scotian Shelf during 1999 and 2000 (Laurinolli et al. 2004). Gastric evacuation models, in conjunction with stomach content data from fish in the wild, were used to estimate total consumption and the proportion of the different prey items consumed by fish populations in order to quantify feeding interactions among species. For this analysis, gastric evacuation rates were taken from the literature to estimate consumption. Consumption rates per day were estimated for 5 cm length groups of fish using the consumption model of dos Santos and Jobling (1995) based on experiments with cod. See Laurinolli et al. (2004) for further details. Consumption was then expressed as population consumption/population biomass for the Ecopath model.

For the 1980-1985 model, estimates from the 1995-2000 model were used in the absence of other data. Where no estimates were available, estimates were taken from the literature.

Diet.

Very little empirical diet data were available for species from the eastern Scotian Shelf for the 1980-1985 period. The few exceptions include silver hake, for which there is good diet data collected by Waldron (1988), grey seals, and some samples of pollock. Diet data were available for some species from surveys that took place on the Scotian Shelf from 1958 to 1969 and these were used in lieu of more recent data. For those species with no diet data available from the eastern Scotian Shelf, diet data collected by the National Marine Fisheries Service from the western Scotian Shelf and Georges Bank were made available (J. Link, NMFS, pers. Comm,). These diet data are not ideal since these diets do not originate from the eastern Scotian Shelf. However, these are the closest systematic and comprehensive diet data available and were thus used. If there were sufficient sample sizes, diets from the western Scotian Shelf were used, and adjusted for prey components where appropriate. In some cases, diets from Georges Bank were also used to supplement poor sample sizes from the western Scotian Shelf. In cases with no diet information from any of these sources diet data from the literature for similar systems was used.

For the 1995-2000 model, stomach data were available from research surveys conducted on the eastern Scotian Shelf in 1999 and 2000. Percent diet composition was estimated from the total consumption estimates described above. See Laurinolli et al. (2004) for further details.

Given the level of uncertainty in the estimates of diet composition, once diets were estimated for the two time periods, they were compared and modified to ensure that the same prey species were present in both time periods. This was done to facilitate tropho-dynamic modelling between time periods using Ecopath with Ecosim. In general, prey items were included by either using the value from the other time period, or reducing it by a factor of 10 or 100, and in all cases, the each added prey would be less than 1% of the diet. Details for each functional group are given in Appendix 2. For prey species such as capelin whose biomass was very low in the early period, consumption was assumed to be very small.

DESCRIPTION OF INPUT DATA FOR EACH ECOPATH GROUP

1. CETACEANS

BACKGROUND

The Scotian Shelf provides summer feeding ground for several cetacean species. Whales include fin, *Balaenoptera physalus*, minke, *Balaenoptera acutorostrata*, humpback, *Megaptera novaeangliae*, sperm, *Physeter catodon*, pilot, *Globicephala melaena*, Sei *Balaenoptera borealis* and blue *Balaenoptera musculus*. These species are part of larger populations that migrate to waters off eastern Canada to feed during the summer. Sub-groups of some species may also stay on the Scotian Shelf all year. Dolphins include common dolphins, bottlenose dolphin and Atlantic white-sided dolphin.

CATCH

There is no catch of cetaceans in the study area for either study period as Canada ceased commercial whaling in 1972.

BIOMASS

There are no annual abundance or biomass estimates for cetaceans on the eastern Scotian Shelf. In order to obtain such an estimate, estimates of abundance were provided from the Northeast Fisheries Science Centre's (NEFSC) 1995 summer line-transect abundance survey (the aerial portion) by Dr. Debra Palka, NMFS (Appendix 3). These data were used to represent the 1995-2000 time period. The following whales and dolphins were sighted in the survey: fin whale, minke whale, humpback whale, sperm whale, pilot whale, common dolphins and Atlantic white-sided dolphin. The abundance of each species was multiplied by the mean weight of each species to give biomass, and this biomass was adjusted for the residency period of each species on the eastern Scotian Shelf to give average annual estimates of biomass (Table 1).

Table 1. Abundance, mean weight, residency time and biomass estimates of cetaceans on the eastern Scotian Shelf in 1995-2000.

	No./km^2	Mean body weight (t)	Residence[1]	Density (t/km^2)	Total No.	Total Biomass (t)
Humpback	0.0074	31	0.25	0.0574	189	5868
Sperm	0.0006	40	0.43	0.0104	27	1062
Minke	0.0023	5.6	0.27	0.0034	63	350
Pilot	0.0323	1.4	0.50	0.0226	1669	2308
Fin	0.0071	38.5	0.55	0.1493	397	15276
white-sided dolphin	0.2588	0.4	0.55	0.0171	14559	1747
common dolphin	0.0130	0.3	0.25	0.0002	333	22
TOTAL	0.3189			0.2603	17236	26634

[1] residence is the proportion of the year spent in the study area. These are estimates based on information in the literature.

The estimate of biomass for 1980-1985 was adapted from these data. For most species, in the absence of other information, it is assumed that the abundance of cetaceans on the eastern Scotian Shelf in 1980-1985 is not different from in 1995. We do not know if this is the case for all species. However, the northwest Atlantic humpback population has been increasing by around 6.7% per annum (Barlow and Clapman 1997; P. Hammond, Sea Mammal Research Unit, UK. pers. comm.). Thus, the estimate of 0.0074 whales per km^2 in Appendix 3 is too high. It was reduced by the annual growth rate to a value of 0.0045 whales per km^2 for 1980-1985.

In addition, Sei whales were not sighted in the 1995 survey, although they were caught in the area during the period of the commercial fishery in the 1960s and 1970s. During this time, Sei whales generally occurred in deep waters around 2000 m and made feeding incursions on to the shelf during June and July, and September to October feeding primarily on euphausiids and copepods (Mitchell 1975). These whales are probably still present but were not observed by the survey. A CETAP study for Spring 1978-1982 estimated an abundance of 253 for the Nova Scotia stock of sei whales from Cape Hatteras, NC to Nova Scotia (NOAA 2000). It is assumed that 10% of these animals were present on the eastern Scotian shelf during 1980-1985.

The biomass estimate for all whales in 1980-1985 is 23,480 t. or 0.229 t. km^2.

These estimates are subject to several areas of uncertainty. The abundance estimate from the aerial survey is negatively biased because it was assumed that the probability of detecting an animal, if it were on the transect line, was 1, and there are no dive time corrections (see Appendix 3 for more details). Abundance may fluctuate through time depending on what food sources are available on the Scotian shelf. The residency times are estimates based on information in the literature and consultation with experts. None are considered accurate.

There are thus several areas of uncertainty. A lower bound for the biomass estimate was estimated by assuming that all species other than humpbacks had increased by 4% pa, the maximum net productivity rate assumed by NMFS (NOAA 2000) since 1980. Back-calculating from 1995 produced a biomass estimate of 15, 427 t, 65% of the estimate in Table 1. It was also assumed that all estimates may be underestimates, and the upper bound was assumed to be +20%.

BIOMASS ACCUMULATION

Since there are no separate estimates of biomass for the cetaceans for the two time perionds, there is no biomass accumulation term.

PRODUCTION:BIOMASS

It is assumed that P/B is 0.04 yr^{-1} for both time periods, based on theoretical modelling showing that cetacean populations cannot grow at a rate much greater than 4 % given the constraints of their reproductive life history (Barlow et al. 1995, in NOAA 2000). Note however, that estimates of the growth rate of humpbacks are higher at 6. 7% per annum (see above). Thus in a small unfished population, production can be greater than the intrinsic growth rate.

CONSUMPTION:BIOMASS

A Q/B ratio of 10.17 yr^{-1} for both time periods was taken from consumption estimates in Kenney et al. (1997) for Georges Bank.

DIET

There is little diet information available for other cetaceans for the eastern Scotian Shelf. For this reason, the diets used for cetaceans by Bundy et al. (2000) in the Newfoundland-Labrador Ecopath model were revised for the eastern Scotian Shelf. Sei and fin whales diets were estimated from stomach content data collected from commercial whale kills on the eastern Scotian Shelf from 1967 to 1972 (Sutcliffe and Brodie 1977). Both species feed predominately on zooplankton. Other than the fin whale, the proportions of fish, squid and zooplankton correspond to the proportions given in Kenney at al. (1997). The same diets were used for each species of whales, but the proportional contribution of each differs in the two time periods. See Table 1, Appendix 2 for further details.

2. GREY SEALS

BACKGROUND (Don Bowen, BIO).

The grey seal (*Halichoerus grypus*) is a size-dimorphic member of the Family Phocidae, with males being about 20% longer and 50% heavier than females. Most females give birth to a single pup each year, beginning at age 4 years and continuing for several decades. Grey seals disperse widely over the continental shelf during the non-breeding season (Stobo et al., 1990), but show high levels of philopatry. In the Northwest Atlantic, major breeding colonies are located on the sea ice in the southern Gulf of St. Lawrence and on Sable Island, Nova Scotia. Smaller colonies are found on near-shore islands off Cape Breton and along the Eastern Shore of Nova Scotia (Mansfield and Beck 1977, Hammill et al., 1998). Grey seals are currently the most abundant pinniped species on the Scotian Shelf throughout the year and in the Gulf of St. Lawrence during summer and fall.

Historical population trends of grey seals are poorly known. However, bounty hunting and perhaps other factors reduced grey seal numbers in Eastern Canada to only a few thousand individuals by the early 1960s (Mansfield and Beck, 1977; Zwanenburg and Bowen, 1990). Since then, the most accurate estimates of grey seal pup production come from Sable Island where most pups were tagged between 1962 and 1990 (Mansfield and Beck, 1977; Stobo and Zwanenburg, 1990). However, numbers on Sable Island prior to 1976 were often based on short visits to the island and as a result pup production was generally underestimated (Zwanenburg and Bowen, 1990; Mohn and Bowen, 1996). Between 1976 and 1990, censuses were based on tagging all newly weaned pups. These data showed that the trend in pup production was exponential, at an annual rate of increase of about 13% (Zwanenburg and Bowen, 1990; Mohn and Bowen, 1996). The most recent estimate of pup production on Sable Island was conducted in 1997 using aerial photography. When corrected for the proportion pups seen on the imagery and the proportion of pups born before the survey, estimated total pup production was 25, 400 with approximate 95% confidence limits of 23 500 and 26 900. The 1997 estimate indicates that pup production in this population, now the largest grey seal colony in the world, has been increasing exponentially at an annual rate of 12.8% per year for four decades in the face of considerable environmental variability (Bowen et al. 2003).

CATCH

During 1980-1985, there was a small catch of 100-200 grey seals taken from the Eastern Scotian Shelf (D. Bowen, DFO pers.comm.) This amounts to around 21 t, or 0.0002 tkm^2. A small number of grey seals have undoubtedly continued to be killed but records are incomplete to non-existent.

BIOMASS

The average annual biomass of grey seals on the eastern Scotian Shelf during 1980-1985 was 2, 552 t, or 0.025 t·km^2 and was 14,559 t. or 0.142 t·km^2 in the 1995-2000 time period (Table 2). These values were estimated from an updated version of the grey seal population model presented in Mohn and Bowen 1996 (R. Mohn, DFO, pers, comm.).

Table 2. Estimates of biomass, P/B and Q/B for grey seals on the eastern Scotian Shelf.

	1980-1985	1995-2000
Biomass, t.	2, 552	14, 559
Density, t·km^2	0.025	0.142
P/B, yr^{-1}	0.124	0.124
Q/B, yr^{-1}	11.8	11.8

BIOMASS ACCUMULATION

The population of grey seals has been increasing exponentially since the 1980s. The average annual increase during 1980-1985 was 0.003 t·km^{-2} and 0.017 t·km^{-2} in 1995-2000.

PRODUCTION·BIOMASS

The P/B ratio of 0.124 yr^{-1} was derived from the seal population model presented in Mohn and Bowen 1996 (R. Mohn, DFO, pers, comm.). This value was used for both time periods.

CONSUMPTION:BIOMASS

A consumption to biomass ratio of 11.8 yr^{-1} was estimated from an updated version of the grey seal population model presented in Mohn and Bowen 1996 (R. Mohn, DFO, pers, comm.). This value was used for both time periods.

DIET

The only diet data available for Grey seals on the eastern Scotian Shelf during 1980-1985 was collected from seals on Sable Island as part of a seal worm study from 1983-1984 (Benoit and Bowen 1990). Stomachs were collected every 6 weeks during this period, and prey were recorded as percentage occurrence. There is no easy way to convert % occurrence to % weight, the units used for diets in the Ecopath model. However, this data was used in preference to later diet studies, where samples were collected as scats and prey converted to % weight since the species composition of the ecosystem changed considerably between the early 1980s and the 1990s. Grey seal diet would be expected to reflect this change, and the earlier data are likely to be more representative of the prey consumed at that time.

The diet data for the 1995-2000 time period were taken from two different sampling methods, fecal sampling, and fatty acid analysis (Beck, 2002; Don Bowen, DFO, unpublished data) Table 2a and 2b, Appendix 2.

3. SEABIRDS

BACKGROUND (Falk Heutmann)

Seabird distribution on the Scotian Shelf has been described by Brown *et al.* (1975), Huettmann (2000). The eastern Scotian Shelf is known to carry large numbers of wintering dovekie (*Alle alle*) (Brown 1988), and high numbers of sooty (*P. griseus*) and greater shearwater (*P. gravis*). For species like thick-bilied murre (*Uria lomvia*), common murre (*U. aalge*), Atlantic puffin (*Fratercula arctica*), northern fulmar (*Fulmarus glacialis*), glaucous and Iceland gull (*Larus hyperboreus, L. glaucoides*), the study area generally constitutes their southern wintering range. During spring and fall, the study area also lies on the flyway for Canadian herring gulls (*Larus argentatus*), great black-backed gulls (*L. marinus*), northern gannets (*Morus bassanus)*. During the summer (northern hemisphere breeding season), the study area is also important for Leach's storm petrels (*Oceanodroma leucorhoa*), and also for Wilson's storm petrel (*Oceanites oceanicus*) migrating from the southern hemisphere. While the latter does not breed in the northern hemisphere, it is among the most abundant seabird species in the world. Sightings of birds from other distributional ranges and hemispheres occasionally occur in the study area, too, such as Cory's and Manx shearwater (*Caleonectris diomedea, Puffinus puffinus*) (the latter is an increasing new breeding population), black skimmer (*Rynchops niger*), Flea's petrel (Hooker and Baird 1997), south polar skua (*Catharacta maccormicki*) and others. For further details on background and general ecology of seabirds and the study area see for instance Nettleship and Birkhead (1985), Furness and Monaghan (1987),Gaston and Jones (1998), Huettmann and Diamond (2000), Huettmann (2000).

Quantitative estimates of abundance, biomass and prey consumption of seabirds in the eastern Scotian Shelf were provided from a specially commissioned study by Dr. Falk Heuttman *(http://www.osl.gc.ca/cdeena/en/publications.shtml*). The data used for this study were derived from the PIROP (Programme des Recherches sur les Oiseaux Pélagiques) database, the largest and most detailed data set on seabird abundance and distribution for the study area (for details see Brown *et al.* 1975, Lock *et al.* 1994 and Huettmann 2000). The database covered the period from 1966-1992 and all estimates were averaged over this period. Unfortunately there were insufficient data to analyse them on a finer time scale and thus the same estimates are used in the 1980-1985 and 1995-2000 models.

CATCH

There is no recorded catch of seabirds. There is however likely to be incidental mortality in fishery operations.

BIOMASS

The 10 main species found on the eastern Scotian Shelf and their biomass, seasonally weighted are shown in Table 3. In total, the biomass of seabirds is 1079 t, 0.012 tkm^2.

Table 3. Estimated annual biomass of seabirds on the eastern Scotian Shelf.

Seabird species	Biomass (t)
Greater shearwater	304
Herring gull	282
Wilson's storm petrel	8
Great black-backed gull	281
Northern fulmar	76
Black-legged kittiwake	54
Leach's storm petrel	3
Dovekie	19
Thick-billed murre	43
Sooty shearwater	10
Total Biomass	1079
Density (tkm^2)	0.0120

BIOMASS ACCUMULATION

Since there is insufficient data to produce separate estimates for seabird biomass in 1980-1985 and 1995-2000, there is no biomass accumulation term.

PRODUCTION:BIOMASS

Assumed to be 0.25, after the Newfoundland-Labrador model (Bundy et al. 2000).

CONSUMPTION:BIOMASS

Total annual consumption by seabirds on the eastern Scotian Shelf was estimated to be 147, 124 t, producing a Q/B of 132.5 yr^{-1}. This estimate is based on estimated field metabolic rates of seabirds taken from Anon (2000), and are subject to a great deal of uncertainty. A reasonable range for this uncertainty may be +/- 50%.

DIET

Accurate information on prey consumption by seabirds is rarely available. It is difficult to obtain during field studies and for seabirds at sea, and diet information is derived mostly from colony studies; not enough studies have focussed on pelagic seabirds and their food requirements. In addition, the range of prey taken can be larger than what is known from the colony and few pelagic studies, and it can also vary by season and year. Here, either time- and geo-referenced information from the literature for seabird colonies were used, or information was used from birds collected at sea; most information used in this study was recently compiled for the region of the study area by Anonymous (2000). These data were adapted to the eastern Scotian Shelf - see Tables A3a-3c, Appendix 2 for more details.

4, 5 ATLANTIC COD

BACKGROUND

The 4VsW stock is the only stock of Atlantic cod, *Gadus morhua* in the model area. This stock has been fished, probably for several centuries, but with greatly increased intensity since the 1950s. There has been an overall decline in landings over this time period, culminating in a dramatic stock collapse in 1993. The fishery has remained closed to commerical fishing since then, with a by-catch allowance in other fisheries.

Cod were split into two groups in order to include the effects of trophic ontogeny. This split was determined to be at 4 years, or 40 cm on the basis of the age of 50% maturity, the age of capture in the commercial fishery and the switch from a mainly invertebrate to a mainly vertebrate diet. The age of 50% maturity varied between 3.6 and 4.4 years for females and between 3.4 and 4.5 years for males from 1979 to 1995 with no discernible trend (Trippell et al. 1997). A mean representative age of 50% maturity for 4VsW cod is 4 years. The length at 50% maturity has declined through time. However the average length at 50% maturity was 39.7 cm and 40.9 cm for female and males respectively during 1980-1985. In the commercial fishery, while some fish are caught at ages 2 and 3, age 4 is the main recruiting age to the fishery, 43-45 cm (Mohn et al. 1998). Thus for the purposes of this model, fish aged 0 to 3, fish length ≤ 40 cm were classified as small cod and fish aged 4+ and fish length > 40 cm were classified as large cod.

CATCH

Large cod

The average catch of 4+ cod in 1980-1985 was 51, 974 t (0.508 t·km^2) and in 1995-2000 was 274 t (0.003 t·km^2).

Small cod

The average recorded catch of small cod was 1, 543 t, or 0.015 tkm^2. However, there is evidence that the actual catch of young cod may have been much greater than this. An estimate of young cod discards was derived from the analysis of Fu et al. (2001). The effect of including discards was examined in the Ecopath model.

BIOMASS

Biomass was estimated from q-corrected RV survey data (Table 4).

Table 4. q-corrected RV survey estimates of cod biomass

	1980-1985		1995-2000	
	Biomass	Density	Biomass	Density
Large cod	124651	1.218	7506	0.073
Small cod	77322	0.756	9723	0.095

BIOMASS ACCUMULATION

Overall, there has been a large decrease in the biomass of large cod from over 183,000 t. in 1984 to 1480 t. in 2002. However, the decline in biomass occurred between 1984 and 1995 (Figure 2) and although there is variation in the biomass during the model time periods, there is no overall biomass accumulation. There was a peak in the biomass of small cod during the 1980s, but again there is no overall biomass accumulation in either time period.

PRODUCTION:BIOMASS

Large cod

It was assumed that P/B = Z for the large cod. The average Z for ages 4+ was 0.631 yr^{-1} during 1980-1985 and 1.04 yr^{-1} in 1995-2000 (R. Mohn, DFO, pers.comm.).

Small cod

Catchabilities of cod ≤ 40 cm are very low and thus Z cannot be estimated from a catch curve analysis, or by tracking the numbers of a cohort from RV survey data through time. In this case, SPA data were used to estimate the total production of 1-3 year olds. Annual total production was estimated as the difference in biomass between year n and year n+1, plus losses due to fishing, losses due to seals, losses due to other forms of mortality and losses to the large cod group. P/B was estimated as total production divided by total biomass. As shown in Figure 3, the P/B of young cod remained fairly stable until around 1990. Since 1990, P/B has steadily increased. The high P/B in latter years does not indicate high total production of young cod. Gross production has decreased since 1981 to an all time low (since 1970) in 1992, but biomass is so low, that it creates a high P/B. The average P/B was 1.1 yr^{-1} in 1980-1985 and 2.2 yr^{-1} in 1995-2000.

CONSUMPTION:BIOMASS

There were no consumption estimates available for 4VsW cod during the 1980-1985 study period, so the estimates from the 1995-2000 period were used for both.

Large cod

An annual consumption rate of 1.95 yr^{-1} was estimated from the consumption analysis using cod stomach data collected in 1999 and 2000 from the eastern Scotian Shelf. This value falls within the range of consumption estimates of Atlantic cod in the literature. The range is encompassed by a study of cod off Newfoundland and Labrador (Lilly 1982). The low end of the range is 1.58 yr^{-1}on the Newfoundland-Labrador shelf and the high end is 4.4 yr^{-1} on the Grand Banks.

There are few studies in Canadian waters that can be used here. Lilly *et al.* (1981) estimated consumption by cod, on the basis of an estimated production (mean number at age times somatic growth at age times reproductive growth at age) and a factor equivalent to gross efficiency, to estimate the consumption required to support this production. Mean Q/B estimates for 1980-81 in 2J3KL were 1.58 to 3.16 yr^{-1} and in 3NO were 2.2 to 4.4 yr^{-1}, depending on whether the gross growth efficiency was taken as 0.2 or 0.1.

Waiwood *et al.* (1980) estimated consumption by cod at age in the southern Gulf of St. Lawrence in 1979 from stomach contents and application of the Ursin Fish Growth Theory. Mean Q/B estimates for 3+ age groups was 2.14 yr^{-1}.

Published values of Q/B Pauly (1989) range from 1.41 yr^{-1} (North of Norway) to 2.19 yr^{-1} (Georges Bank). The value of 1.95 yr^{-1} estimated from the eastern Scotian Shelf appears to be a reasonable estimate of the annual consumption rate.

Small cod

An annual consumption rate of 5.03 yr^{-1} was estimated from the consumption analysis using cod stomach data collected in 1999 and 2000 from the eastern Scotian Shelf.

DIET

There were no diet data for cod for the 1980-1985 time period. Diet was estimated using several alternate diet sources: data from the western Scotian Shelf for the 1980s (J.Link, NMFS, Pers. Comm); DFO diet data from the 1960s (Laurinolli et al. 2004) and diet data from the eastern Scotian Shelf in 1999 and 2000. These data are given in Tables 4 and 5, Appendix 2.

Diet data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 144 for large cod and 345 for small cod (Tables 4 and 5, Appendix 2).

6, 7 SILVER HAKE

BACKGROUND

There is one stock of Silver hake on the Scotian shelf, covering NAFO divisions 4VWX. Silver hake migrate between 4VsW and 4X, and the proportion of the stock in either area varies with time. In general there is a greater proportion of the stock in 4VsW: during 1980 to 1985, 68 % of the stock was within 4VsW while the average proportion since 1970 within 4VsW was 62%. Silver hake are also found both on the shelf and the shelf slopes. The stock increased from the late 1970s to a high in the mid 1980s and then decreased to the 1970s level by 1989. There has been no trend in biomass since that time.

The silver hake fishery was almost exclusively pursued by distant water foreign fleets. Prior to 1977 and the extension of jurisdiction, the fishery was unrestricted by area season and mesh size. Post 1977, fishing was limited to the seaward side of the small mesh gear line, or effectively, west of Sable Island, to the shelf edge and seawards. Since 1995 there has been a growing Canadian fishery for silver hake and this is pursued in and around Emerald and Le Have basins, and since 1998 the Canadian fleet has caught more annually than the offshore fleet (Showell and Fanning 1999).

Silver hake were split into two groups in order to allow for the effects of trophic ontogeny. The age and size of the split should represent the change from juveniles to adults, changes in diet and age of capture by commercial fisheries. In the case of silver hake, the age of maturity is 2 to 3 years old (Scott and Scott 1988) and silver hake are fished from aged 1 onwards. However, fish are considered to be fully recruited to the fishery by age 3 and are all mature at age 3. The main changes in the diet composition occur in two steps at ages 3 and 6, with a shift from invertebrates to fish. Cannibalism starts at around age 4 (Table 5.04, Waldron 1988). The age split for silver hake was therefore made at age 3. Age 3 corresponds to approximately 30 cm (Showell 1997a). Thus for the purposes of this model, fish aged 0 to 2, fish length ≤ 30 cm were classified as small silver hake and fish aged 3+ and fish length > 30 cm were classified as large silver hake.

CATCH

Catch data were taken from the NAFO statistics for 4VsW, and split into the two age groups on the basis of the catch at age for 4VWX (Showell 1997b). A Kolmogorov-Smirnov test indicated that the age structure in 4VsW is not different from the age structure in 4X during the summer surveys. Thus catch at age for 4VWX can be used to represent catch at age in 4VsW (Table 5). During 1980-1985, 95% of the silver hake catch of both age groups was taken from 4VsW, while in 1995-2000 this the proportion from 4VsW was 81 %.

Table 5. Average catch of large and small silver hake from 4VsW in 1980-1985 and 1995-2000.

	1980-1985		1995-2000	
	Catch (t)	Catch density ($t{\cdot}km^2$)	Catch (t)	Catch density ($t{\cdot}km^2$)
Large silver hake	42, 116	0.411	6,145	0.060
Small silver hake	11, 769	0.115	15,616	0.153

BIOMASS

Seasonal data from RV surveys for March (1979-1984), July (1970-2001) and Fall (1978-1984) show that there are seasonal differences in RV biomass but that these are not consistent through time. In four of the seven comparable years, the summer RV biomass is lower than the seasonal average. Since silver hake move between 4VsW and 4X, these seasonal differences probably reflect these movements.

Biomass was estimated in 3 ways for silver hake (Table 6)

1. Trawlable biomass was estimated from the RV survey
2. q-adjusted biomass was estimated from the RV survey and estimated q-at-length
3. 4VsW biomass was estimated from SPA biomass estimates for 4VWX. This data set begins in 1983, so the estimate is an average of 1983-1985.

Table 6. Comparison of 4VsW silver hake biomass (t) estimates

1980-1985

	Small biomass 0-2	Large biomass 3+	Total biomass
RV trawlable Biomass	15887	16424	32311
q-adjusted Biomass	328736	191448	520184
SPA Biomass (1983-1985)	71226	81415	156241

1995-2000

	Small biomass 0-2	Large biomass 3+	Total biomass
RV trawlable Biomass	17028	4197	21225
q-adjusted Biomass	379377	50455	429832
SPA Biomass (1995-1999)	54074	49779	103853

There are considerable differences in these estimates. The RV trawlable biomass is too low, for we know that a groundfish trawl does not catch silver hake well. The q-adjusted RV estimates are several times the SPA estimates. The q-adjusted estimates were used for the initial input parameter (Table 7).

Table 7. Input biomass estimates for large and small silver hake.

	1980-1985		1995-2000	
	Biomass (t)	Density ($t \cdot km^2$)	Biomass (t)	Density ($t \cdot km^2$)
Large silver hake	191448	1.87	50455	0.49
Small silver hake	328736	3.21	379377	3.71

BIOMASS ACCUMULATION

There was no clear increase or decrease in silver hake biomass during the two time periods, although, as with Atlantic cod, biomass of large silver hake has decreased since the 1980s and is currently low. The biomass of small silver hake has been variable, with no trend (DFO, *In press*).

PRODUCTION:BIOMASS

Silver hake P/B was estimated from RV survey total mortality and from SPA data (Table 8). RV estimates of total mortality for 1980-1985 were taken from Showell and Fanning (1999) and for 1995-2000 were from M. Showell, DFO, pers. comm. SPA data were used to estimate the total production of the two age groups. For the adults, annual total production was estimated as the difference in biomass between year n and year n+1, plus losses due to fishing and losses due to other forms of mortality. For the juveniles, annual total production was estimated as for the adults, plus losses to the large silver hake group. P/B was estimated as total production divided by total SPA biomass. The P/B of both large and small silver hake varies over time, but there is no clear trend (Figure 4).

Table 8. Estimates of P/B for large and small silver hake for 1980-1985 and 1995-2000.

	1980-1985		1995-2000	
	P/B from SPA (yr^{-1})	P/B = Z (yr^{-1})	P/B from SPA (yr^{-1})	P/B = Z (yr^{-1})
Large silver hake	1.153	0.8-1.2[1]	0.934	0.845[2]
Small silver hake	1.017	0.38-0.8	1.069	0.845

[1] The 2-year average of Z for 4-5 year olds was 0.8 in 1984 and 1.1 in 1985, and for 6-7 year olds was 0.8 in 1984 and 1.2 in 1985.

[2] The same value was used for large and small silver hake since the Z estimate is for 2-4 year olds.

Large silver hake

Estimates of P/B and Z are high, and all fall in the range 0.8 to 1.2 for both time periods. Estimates of total mortality are lower than the estimates of SPA P/B. The range of estimates was used, with a point estimate of 1.153 yr^{-1} in 1980-1985 and 0.934 yr^{-1} in 1995-2000.

Small silver hake

Estimates of P/B and Z are high, and all fall in the range 0.8 to 1.1 for both time periods, excluding the minimum of 0.38 yr^{-1}. This was not used because it only applies to ages 2-3, whereas the small silver hake include younger age groups that are likely to be subjected to higher mortality rates. Both P/B and Z estimates are similar for the two time periods. Estimates of total mortality are lower than the estimates of SPA P/B. The range of estimates was used, with a point estimate of 1.017 yr^{-1} in 1980-1985 and 1.069 yr^{-1} in 1995-2000.

The P/B and Z estimates are higher for the adults than for the juveniles. This is surprising, since generally, young fish grow more rapidly than older fish. However, silver hake are a fast growing fish and most do not survive past 5 years old.

CONSUMPTION:BIOMASS

Consumption to biomass for 1980-1985 was estimated from daily ration data given in Waldon (1988). Waldron's estimates of daily ration fall in the range of estimates available in the literature, ranging from 3.18 % of body weight for 1 year olds to 1.14 % for 10 year olds. Table 9 gives three estimates of annual Q/B, based on different assumptions concerning the number of days spent feeding each year. It was assumed that silver hake feed for 270 days, and the upper and lower bounds were the assumption of 365 and 180 days feeding respectively.

Table 9. Estimates of Q/B yr^{-1} for large and small silver hake in 1980-1985. Estimates vary with the number of days that silver hake are assumed to feed.

No. days spent feeding	Juveniles	Adults
365	10.508	10.030
270	7.773	7.420
180	5.182	4.946

For the 1995-2000 time period, an annual consumption rate of 5.8 and 5.5 yr^{-1} was estimated for the small and large silver hake from the consumption analysis using silver hake stomach data collected in 1999 and 2000 from the eastern Scotian Shelf.

DIET

Waldron (1988) conducted a large study of silver hake stomach contents on the Scotian Shelf from 1981 to 1986, during February to October (excluding March). Over 11, 000 stomachs were collected from research vessels and from commercial fishing vessels. Of these, 8310 contained at least one prey item, and detailed gut analysis was conducted on 2855 of these stomachs. The diet data by age from Table 4.06 in Waldron (1988) were used here. They were separated into the large and small groups defined here, and a weighted average diet for each group obtained by weighting by SPA biomass. See Tables 6 and 7, Appendix 2.

Diet for 1995-2000 was taken from the stomach survey conducted on the Scotian Shelf in 1999 and 2000 (Tables 6 and 7, Appendix 2).

8 HADDOCK

BACKGROUND

There are two stocks of haddock (*Melanogrammus aeglefinus*) on the Scotian Shelf, NAFO Divisions 4TVW in the east and 4X in the west. Most of the 4TVW stock occurs on the offshore banks of the eastern Scotian shelf, and for the purpose of this model, can be considered a unitary stock: the 1980-1985, summer RV survey demonstrates that on average, 96.6 % of the haddock biomass was found in 4VsW.

Haddock were very abundant on the eastern Scotian Shelf during the 1960s and then again during the 1980s. However by the early 1990s the stock was severely reduced and in 1993 a moratorium was placed on the haddock fishery. Since then, the haddock stock has experienced two year classes which are larger than any seen in the available time series (Frank et al. 2001, Mohn and Simon 2002). Abundance of haddock has reached high levels once more, but biomass is still low due to changes in growth rate. Few haddock are larger than 43 cm (Frank et al. 2001).

CATCH

The catch data was taken from NAFO and ZIF data. The catch in 1980-1985 was 12,742 t (0.124 tkm^{-2}), while in 1995-2000, after the moratorium, it was 126 t. (0.001 tkm^{-2}).

BIOMASS

There are three sources of biomass estimates for haddock: RV trawlable biomass, catchability adjusted biomass and SPA biomass estimates (Table 10).

Table 10. Haddock biomass estimates using three methods for 1980-1985 and 1995-2000.

	Biomass		Density	
	1980-1985	1995-2000	1980-1985	1995-2000
SPA Biomass	65173	42387	0.637	0.414
RV Trawlable Biomass	86392	50615	0.844	0.495
q-adjusted RV Biomass	112016	80281	1.095	0.785

The RV trawlable biomass is in the middle of this range and this estimate was used for both time periods.

PRODUCTION:BIOMASS

P/B was estimated from the SPA model for 4TVW haddock as 0.45 yr^{-1} in 1980-1985 and 0.51 yr^{-1} in 1995-2000 (Table 11., B. Mohn, DFO, pers. Comm.).

CONSUMPTION:BIOMASS

There were no consumption data available for the 1980-1985 time period. For the 1995-2000, a value of 5.19 yr^{-1} was estimated from the consumption analysis using haddock stomach data collected in 1999 and 2000 from the eastern Scotian Shelf (Table 11). This contrasts with an estimate of 3 yr^{-1} from Georges Bank (Pauly 1989). These values may be considered indicative of the range of possible values of Q/B. Given that the 1995-2000 value was derived from the eastern Scotian Shelf, and we do not know if haddock Q/B has changed, this value was used for both time periods.

Table 11. Estimates of haddock P/B and Q/B for 1980-1985 and 1995-2000.

	1980-1985	1995-2000
P/B (yr^{-1})	0.45	0.51
Q/B (yr^{-1})	5.19	5.19

DIET

The haddock diet for the 1980-1985 model was derived from empirical diet studies on the western Scotian Shelf (J. Link. NMFS, pers. Comm.) and from older diet studies on the Scotian Shelf (Kohler and Fitzgerald 1969). The details are given in Table A. 8. For the 1995-2000 model, diet estimates from the DFO stomach survey of eastern Scotian Shelf were available (Table 8, Appendix 2) .The diets were modified slightly so that the same prey species would be present in both time periods.

9. AMERICAN PLAICE

BACKGROUND

American plaice (*Hippoglossoides platessoides*) has a widespread distribution, occurring on both sides of the Atlantic. It is a bottom dwelling flatfish, and in the western Atlantic occurs from the Arctic to USA waters. On the eastern Scotian Shelf, there is one population of American plaice in NAFO Subdivision 4Vn and one in NAFO Subdivision 4Vs. It is managed as a component of a flatfish species complex comprising American plaice, yellowtail flounder and witch flounder and winter flounder in NAFO Division 4VW. With the exception of witch flounder since 1996, the flatfish complex has been managed as a whole with no separation of the TAC at the species level. This has implications for the catch statistics, which may be unreliable for any individual species (Fowler and Stobo 2000).

Catches of American plaice were high until the extension of jurisdiction, after which they fell continuously, together with the biomass, to the early 1990s when the groundfish moratorium was imposed in 1993. Size at age and size of maturity of American plaice have decreased, with a large proportion of the stock reaching maturity before it is recruited to the fishery. This could be a response to intense fishing pressure (Fowler and Stobo 2000)

CATCH

Catch data were taken from NAFO and ZIF databases (Table 12). Catches have steadily declined since the 1970s, and by a factor of 10 from 1980-1985 to 1995-2000.

BIOMASS

The RV trawl survey biomass has declined steadily since the 1970s to the mid 1990s, since when it has stabilized. The RV biomass estimates of American plaice were corrected for catchability (Table 12).

Table 12. Input parameter estimates for American plaice on the eastern Scotian Shelf.

	1980-1985	1995-2000
Catch (t)	5651	530
RV Biomass (t)	37,900	14,567
Q-adjusted Biomass (t)	110222	61840
Biomass Density (t·km^2)	1.08	0.60
Biomass Accumulation (t·km^2)	0.033	0
P/B (yr^{-1})	0.25	0.21
Q/B (yr^{-1})	1.2	1.2

BIOMASS ACCUMULATION

The total biomass of American plaice has gradually declined from the beginning of the RV times series in 1970 to around 1994 (Figure 5). This decline in biomass is represented in Ecopath by the inclusion of a biomass accumulation term (BA). This was estimated as –0.021 tkm^2 from a regression of the q-adjusted biomass on the years 1975-1995. Since the mid-1990s, the biomass has shown no trend, so no biomass accumulation term is used for the latter period.

PRODUCTION:BIOMASS

The production was estimated from the following relationship, P=MB+C and then expressed as a proportion of biomass, P/B. It was assumed that M=0.2. With the biomass and catch described above, this gives a P/B=0.25 yr^{-1} in 1980-1985 and 0.21 in 1995-2000 (Table 12).

CONSUMPTION:BIOMASS

There were no consumption data available for the 1980-1985 time period for American plaice on the eastern Scotian Shelf, For the 1995-2000, a value of 1.2 yr^{-1} was estimated from the consumption analysis using American plaice stomach data collected in 1999 and 2000 from the eastern Scotian Shelf (Table 12). This value is very similar to a mean Q/B for American plaice of 1.26 estimated from Zamarro (1992) for American plaice on George's Bank (Bundy et al. 2000). Given the similarity of these independent estimates, the value of 1.2 yr^{-1} was used for both time periods.

DIET

The diet for the 1980-1985 time period was estimated from diet data for American plaice from Georges Bank and the western Scotian Shelf (Jason Link, NMFS, pers comm). Diet data were available for the 1970s, 1980s and 1990s for Georges Bank and the western Scotian Shelf. In all areas and all years, the diet was similar with 75-91% of the diet composed of echinoderms. Given this consistency of diets, diet data from the western Scotian Shelf for the 1970s was used the represent the 1980s diet on the eastern Scotian Shelf because it has a sample size of 640, where as the other years and areas were less than 66 (Table 9, Appendix 2).

For the 1995-2000 model, diet estimates from the eastern Scotian Shelf were available. The diets for both time periods were modified slightly in order to include the same prey species in both time periods (Table 9, Appendix 2).

10, 11. HALIBUTS

BACKGROUND

Two species of halibut were grouped: Atlantic halibut H*ippoglossus hippoglossus* and Greenland halibut, or turbot, *Reinhardtius hippoglossoides*. Both have putative population distributions wider than the eastern Scotian Shelf: Atlantic halibut is managed across both the Grand Banks and the Scotian Shelf (NAFO Divisions 4VWX3NOPs) and turbot is distributed east and north of the Grand Banks. Turbot have an episodic pattern of occurrence on the eastern Scotian Shelf, and these are associated with colder temperatures. The abundance of turbot has increased 10 fold since the mid-1980s, in concert with cooling in the area from the mid-1980s until the late 1990s. Although the abundance of small Atlantic halibut has increased, total biomass has decreased between the model time periods. Both halibuts are large, long-lived piscivores. Neither species are very abundant in the model area.

The halibuts were split into two groups in order to allow for the effects of trophic ontogeny. The age and size of the split should ideally represent the change from juveniles to adults, changes in diet and age of capture by commercial fisheries. In the case of Atlantic halibut in the northwest Atlantic, the size of 50% maturity is reported to have decreased from 84 cm for males and 98 cm for females in the 1960s to 66 cm and 70 cm for males and females respectively from 1970-1979 (Scott and Scott 1988). Since 1994, fish less than 81 cm are not retained in the fishery. There are three stages in the diet composition; fish less than 30 cm eat invertebrates, fish between 30 and 66 cm eat invertebrates and fish, while fish greater than 66 cm are piscivores.

In the case of turbot the length of 50 % maturity appears to be 75 cm for males and 115 cm for females (DFO 2001a). In Newfoundland, they mature at lengths 63-98 cm for females and 51-96 cm for males Morgan and Bowering (1995). The main ontogenic change in diet occurs when Greenland halibut are about 20 cm (Bowering and Lilly 1992).

The 3 criteria for demarcating small or small fish from large or large fish occur at different sizes and ages for both species of halibut. A size split of 65 cm was chosen because is an approximation of the size of 50 % maturity of Atlantic halibut and is the size at which the diet changes to totally piscivorous. In addition, it essentially encompasses the turbot population as small halibuts (until 1999, all the turbot on the eastern Scotian Shelf were less than 65 cm for the two time periods).

CATCH

Catch data were taken from NAFO and ZIF databases (Table 13). Catches of Atlantic halibut were split into large small fish on the basis of the proportions at length in the Atlantic halibut catch for 1998 and 1999 (Zwanenburg, DFO, Pers, comm.). The turbot catch is all assumed to be less than 65 cm. The catch of both size groups and both species has decreased from the 1980s to the current time period.

Table 13. Average catch (t) of Atlantic halibut and turbot, 1980-1985 and 1995-2000.

		Atlantic halibut	Turbot	Total
1980-1985	<=65	9	26	36
	>65	868	0	868
1995-2000	<=65	3	17	21
	>65	331	0	331

BIOMASS

The biomass is estimated by the RV survey (q-adjusted), but the survey does not sample either of these species well, for catch rates are variable across years. Atlantic halibut migrate over long distances and their distribution is far greater than the eastern Scotian Shelf. The q-adjusted RV trawl survey biomass of small Atlantic halibut has been variable since 1970, but is higher in the 1995-2000 time period than the 1980-1985 time period (Figure 6). The biomass of the large Atlantic halibut has also been variable, but the biomass in 1995-2000 is 20% of the biomass in 1980-1985. Turbot have different trends. The small turbot have increased greatly since the late 1980s, while large turbot have been minimal throughout most of the time series, but have increased in recent years (Table 14). In the 1980-1985 time period, large and small Atlantic halibut had a much greater biomass than turbot: in the 1995-2000 time period, that situation has reversed. The total biomass of halibuts in greater in latter years due to the increase in turbot.

Table 14. q-adjusted biomass estimates (t) of Atlantic Halibut and Turbot.

	Atlantic halibut	Turbot	Atlantic halibut	Turbot	Atlantic	Turbot	Halibuts (t)	Halibuts (t)	Halibuts ($t{\cdot}km^2$)	Halibuts ($t{\cdot}km^2$)
	≤ 65	≤ 65	> 65	> 65	ALL	ALL	≤ 65	> 65	≤ 65	> 65
1980-1985	1610	63	5454	31	7064	94	1673	5485	0.016	0.054
1995-2000	2687	7658	1058	74	3746	7732	10346	1132	0.101	0.011

BIOMASS ACCUMULATION

There is no clear trend in the biomass of large halibuts during the RV time series. However, the biomass of small halibuts has increased steadily since the late 1980s. This is represented by the inclusion of a positive biomass accumulation term of 662 $t{\cdot}yr^{-1}$ or 0.006 $t{\cdot}km^2\ yr^{-1}$ in the 1995-2000 model.

PRODUCTION:BIOMASS

P/B for the large halibut was taken from Atlantic halibut mortality data estimated for the eastern Scotian Shelf, using a growth model from the Gulf of St. Lawrence (Zwanenburg et al. 1997). The average of the male and female mortality for 1980-1985 was 0.23 yr^{-1}. The average in 1995-2000 has increased to 0.5 yr^{-1}, due to increased fishing pressure on Atlantic halibut. There are no estimates of mortality for turbot on the eastern Scotian Shelf. Their mortality is likely to be low given the low catch and the rapidly increasing biomass. Since turbot are only a small proportion of the large halibut biomass, the estimates of Z for Atlantic halibut were used to represent the large halibut P/B in both time periods (Table 15).

In the absence of estimates of the P/B or mortality for either of the small halibut species, it was assumed that it was twice the 1980-1985 large halibut value, that is 0.46 yr^{-1}.

CONSUMPTION:BIOMASS

There are no estimates of food consumption for Atlantic halibut in the model area or the northwest Atlantic. However, there are estimates for Greenland halibut for the shelf and slope areas of the Northwest Atlantic from Davis Strait to eastern Newfoundland Chumakov and Podrazhanskaya (1986). From 76,700 stomachs taken during surveys in 1969-81, the daily food requirements were found to range from 1.2% of body weight at age 5 to 0.5% at ages 14-17 years. These data were used by Bundy et al. (2000) to estimate consumption rates of 1.5 yr^{-1} for Turbot > 40 cm and 3.4 yr^{-1} for turbot ≤ 40 cm.

These can be compared to assuming a P/Q ratio of 0.15, which gives a Q/B estimate of 1.53 yr^{-1} for 1980-1985 and 3.3 yr^{-1} for 1995-2000 for large Atlantic halibut. The Q/B estimates for the 1980s are comparable, but due to the higher mortality estimate for the 1990s, the Q/B estimate for the 1990s is twice that for the 1980s. A small halibut Q/B of 2.75 yr^{-1} was estimated from the consumption analysis using turbot stomach data collected in 1999 and 2000 from the eastern Scotian Shelf (Table 15). This value was used for both time periods since it is derived from the model area.

Table 15. Estimates of P/B and Q/B for the halibut group, 1980-1985 and 1995-2000.

Parameter	Group	1980-1985	1995-2000
P/B yr^{-1}	Large halibuts	0.23	0.5
	Small halibuts	0.46	0.46
Q/B yr^{-1}	Large Atlantic Halibut (P/Q=0.15)	1.53	3.3
	Large turbot	1.5	
	Small halibuts	2.75	2.75

DIET

There are no large halibut diet data from the eastern Scotian Shelf for the 1980-1985 time period and minimal samples from the 1990s. In the absence of this data, diet data from seasonal RV surveys conducted between 1958 and 1969 were used. The total sample size is small (32) but is comparable to diet data from western Scotian Shelf. This data was used for large halibuts for both time periods. Further details are given in Table 10, Appendix 2.

The small halibut diet for the 1980-1985 time period was estimated from stomachs collected from the of seasonal RV surveys of the Scotian Shelf conducted between 1958 and 1969 (for the 4VsW area). The total sample size was 148. The 1995-2000 diet was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 236. The diets for both time periods were modified slightly in order to include the same prey species in both time periods. Further details are given in Table 11, Appendix 2.

12. FLOUNDERS

BACKGROUND

Yellowtail flounder (*Limanda ferruginea*), witch flounder (*Glyptocephalus cynoglossus*) winter flounder (*Pseudopleuronectes americanus*), fourspot flounder and brill are bottom-dwelling flatfish with small mouths that are aggregated into a functional group called flounders. In a fisheries context, yellowtail flounder, witch flounder and winter flounder have been managed together with American plaice as a stock complex in NAFO Division 4VW since 1994. However American plaice were not included in the flounder functional group because they have larger mouths and are more piscivorous (see above).

Before 1994, the flatfish complex was managed under a TAC for the whole Scotian Shelf (4VWX) and excluded winter flounder, which is an inshore species. These species are managed as a complex because of the unreliability of the fishery statistics. With the exception of winter flounder, which fetches a higher market price, these species were often not distinguished in the statistics.

Flounders were subjected to high fishing pressure during the 1970s before the extension of jurisdiction in 1977. Since then, biomass has decreased to the point where fishery sized yellowtail flounder are no longer available on the fishing grounds (DFO, 2000b).

CATCH

Catch data were taken from NAFO and ZIF databases (Table 16). Catches have steadily declined since the 1970s, and by a factor of 4 from 1980-1985 to 1995-2000.

Table 16. Catch of Flounders in 1980-1985 and 1995-2000

	1980-1985	1995-2000
Catch, t.	2617	641
Catch Density, t·km^2	0.026	0.006

BIOMASS

The RV trawlable biomass and q-adjusted biomass estimates for the 5 flounder species are shown in the table below in Table 17. The q-adjusted estimates were used for both time periods.

Table 17. Flounder biomass estimates (t) from the RV Survey (trawlable biomass) and adjusted for catchability averaged over 1980-1985.

	1980-1985		1995-2000	
	trawlable biomass	q-adjusted biomass	trawlable biomass	q-adjusted biomass
Yellowtail flounder	18362	60339	10758	57949
Witch flounder	3011	4373	1611	5697
Winter flounder	911	1502	1978	4745
4spot flounder	9		5	
Brill	106		2	
Total	22400	66667	14354	68400
Biomass density	0.219	0.652	0.140	0.668

BIOMASS ACCUMULATION

The total biomass of flounders has gradually declined from the beginning of the RV times series in 1970 to around 1994 (Figure 7). This decline in biomass is represented in

Ecopath by the inclusion of a biomass accumulation term (BA). This was estimated as –0.009 tkm^{-2} from a regression of the q-adjusted biomass on the years 1975-1996.

PRODUCTION:BIOMASS

The production was estimated from the following relationship, P=MB+C and then expressed as a proportion of biomass, P/B. It was assumed that M=0.3, after Pitt (1975). With the biomass and catch described above for the flounders during 1980-1985, this gives a P/B=0.341 yr^{-1} and 0.311 for 1980-1985 and 1995-2000 respectively.

CONSUMPTION:BIOMASS

There were no consumption to biomass estimates for 1980-1985, so the 1995-2000 estimates was used for both time periods (Table 18). These were estimated from the consumption analysis using diet data from seasonal yellowtail, witch and winter flounder stomach samples collected from the eastern Scotian Shelf in 1999 and 2000.

Table 18. Estimates of consumption to biomass ratios for the flounder species, yr^{-1} (sample size in brackets).

	Witch flounder	Yellowtail flounder	Winter flounder
Spring	2.8 (186)	6.7 (90)	1.1 (1)
Summer	2 (373)	2.7 (588)	2.2 (75)
Annual	2.4	4.7	1.7

The biomass weighted average of the annual estimates is 4.0 yr^{-1}. However, this influenced by the high Spring estimate for yellowtail flounder. A more representative values of 2.7 yr^{-1} was used.

DIET

The diets of yellowtail flounder, witch and winter flounder were estimated from NMFS stomach contents data for the western Scotian Shelf and Georges Bank, see Table 12, Appendix 2. The flounder diet was estimated as the weighted average of these 3 diets.

For the 1995-2000 model, diet estimates from the DFO stomach sampling of the eastern Scotian Shelf were available (Table 12, Appendix 2).

13. SKATES

BACKGROUND

Five species of skate occur on the eastern Scotian Shelf: Thorny Skate (*Raja ocelleta*), Winter Skate (*R. radiata*), Smooth Skate (*R. senta*), Little Skate (*R. erinacea*) and Barndoor Skate (*R. laevis*). Until 1994, there was no regulated fishery for skates, although recorded landings of skates, mostly by foreign fleets, were very high in the past. Due to the unregulated nature of the fishery, actual catches would have been even. In 1994 an exploratory directed fishery for skate began in NAFO Divs 4VsW higher (Simon and Frank 1995). Only Thorny and Winter skate occur in much abundance, and all except Little skate have shown considerable declines in abundance since the early 1970s. Barndoor Skate now is listed as endangered by COSEWIC and Thorny skate is now being considered for COSEWIC status.

CATCH

During 1980-1985, the average annual recorded landings of skates from 4VsW were 315 tons. As noted above, there was likely a considerable amount of unreported by-catch of skates during that time. The bycatch of skates from 1989 to 1992 was estimated from observations by the Scotia-Fundy Observer Program of the foreign and Canadian fisheries . The average total bycatch for this period was 3563t or 0.035 t·km^{-2}. Since effort in 1980-1985 and 1989-1992 was similar, bycatch in 1980-1985 should be equivalent to that seen during the 1989 to 1992 period. No discard estimate is available for the 1995-2000 time period. However, given the reduction in effort since 1993 due to the closures of the cod and haddock fisheries and the reduction in quotas of other species, the level of discarding has been much reduced since 1993. The landed catch of skate in 1995-2000 was 1049 t (0.010 t·km^{2}).

BIOMASS

The RV trawlable biomass and q-adjusted biomass for the 5 skate species is shown in the table below (Table 19). Note that there is no RV catch of Barndoor skate.

Table 19. Skate biomass estimates from the RV Survey (trawlable biomass) and adjusted for catchability averaged over 1980-1985.

	1980-1985		1995-2000	
	trawlable biomass	q-adjusted biomass	trawlable biomass	q-adjusted biomass
Thorny Skate	14929	22718	5058	7537
Winter Skate	4578	4589	2028	2082
Smooth Skate	479	546	195	294
Little Skate	207	208	138	162
Barndoor Skate	0	0		
Total	20194	28061	7418	10074
Biomass Density	0.197	0.274	.072	0.098

BIOMASS ACCUMULATION

The total trawlable biomass of skates has declined from the beginning of the RV times series in 1970 to around 1994 (Figure 8). Since then it has stabilised at a low level. The total q-adjusted skate biomass has declined through the time series to 2001. This decline in biomass is represented in Ecopath by the inclusion of a biomass accumulation term (BA) in the 1980-1985 model. This was estimated as –0.015 tkm^{2} from a regression of the q-adjusted biomass on the years 1975-1996.

PRODUCTION:BIOMASS

The production was estimated from the following relationship, P=MB+C and then expressed as a proportion of biomass, P/B. A value of 0.1 yr^{-1} was used for natural mortality. If the reported catch is used, then P/B=0.111 yr^{-1}. If catch is estimated as the landings plus the estimate of discards, then P/B = 0.238 yr^{-1}. Given the uncertainty in the catch, this was simply rounded to 0.2 yr^{-1}. A P/B of 0.187 yr^{-1} was estimated for 1995-2000 using the same method, and this was also rounded to 0.2 yr^{-1}.

CONSUMPTION:BIOMASS

There were no consumption to biomass estimates for 1980-1985, so the 1995-2000 estimate of 1.88 yr^{-1} was used for both time periods. This was estimated from the consumption analysis using diet data from seasonal thorny skate stomach samples collected from the eastern Scotian Shelf in 1999 and 2000.

DIET

Skate diet was estimated as the weighted average of thorny skate and winter skate diets from NMFS data for the western Scotian Shelf and Georges Bank. For the 1995-2000 model, diet estimates from the DFO stomach sampling of the eastern Scotian Shelf were available (Table 13, Appendix 2).

14. SPINY DOGFISH

BACKGROUND

Spiny dogfish, *Squalus acanthus*, is a migratory small shark distributed in the Northwest Atlantic from Labrador to Florida, although is most abundant between Nova Scotia and Cape Hatteras. They winter in the more southern part of their range and migrate northwards in the summer to feeding grounds off the US and Nova Scotia. They are concentrated in the western part of the Scotian Shelf, but also occur on the eastern Scotian Shelf. They are a long-lived slow growing species, and have traditionally been caught as a by-catch in Canadian (and US) fisheries. More recently however, dogfish have been targetted and concerns have been raised concerning health of the stock. Dogfish are generally considered to comprise one stock in the northwest Atlantic.

CATCH

Catch data were taken from NAFO and ZIF databases. Catches have generally been low, with the exception of a peak in catches by the former Soviet Union of 4300 tons in the early to mid-1970s. Since then catches have been generally less than 500 tons, decreasing to less than 40 tons during the 1990s. The average catch in 1980-1985 was 310 t., and in 1995-2000 was 44 t. These catch estimates do not take into account estimates of discards which were reported to be high during the 80s since spiny dogfish were considered to be a "trash fish".

BIOMASS

Spiny dogfish are a migratory, bentho-pelagic species and are not sampled well by the RV Survey. Their biomass has a strong seasonal distribution and survey catches are much higher in spring than in summer or the fall. Overall, their biomass has decreased on the eastern Scotian Shelf: this could be due to distributional changes, to a decrease in their population abundance, or both. Spring, summer and fall survey estimates of biomass were available from 1979-1984 and the average of these was used to estimate the biomass for the 1980-1985 time period (Table 20). Only spring and summer surveys have been conducted since 1984, so for the 1995-2000 time period, the summer was given a weighting of 2/3 and the spring 1/3. This was assumed to represent the average annual biomass. The biomass in the 80s is twice that observed in the 1995-2000.

Table 20. Input parameter estimates for spiny dogfish.

	1980-1985	1995-2000
Catch, t	310	44
Biomass, t	24688	10705
Density, t·km^{2}	0.241	0.105
P/B yr^{-1}	0.23	0.21
Q/B yr^{-1}	2.6	2.6

PRODUCTION:BIOMASS

There are no direct estimates of production of spiny dogfish, but it is likely to be low because they have slow growth and are k strategists. Production is estimated here from the relationship P=M*B+C, assuming a natural mortality of 0.2 yr^{-1} (Table 20).

CONSUMPTION:BIOMASS

There are no estimates of Q/B for spiny dogfish on the eastern Scotian Shelf, but there are some available from British Columbia: (Jones and Geen 1977) estimated a Q/B of 2.7 yr^{-1} and Tanasichuk et al. 1991 gave an estimate of 2.5 yr^{-1}. A value of 2.6 yr^{-1} is used here to represent both time periods.

DIET

Diet for the 1980-1985 time period was estimated from data collected during the 1980s from George's Bank (J. Link, NMFS, Pers. Comm). Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 81. The diets for both time periods were modified to include species present in the other time period. See Table 14, Appendix 2 for further details.

15. REDFISH

BACKGROUND

Redfish are long-lived, slow growing, semi-pelagic fish that occur in depths from 100 - 700m. Unlike most other marine teleost fish species, redfish are viviparous. Mating occurs in the fall and females release live young from April to July. They reach a commercial age at approximately 8 to 10 years at a length of 25 cm. They are distributed on both sides of the Atlantic and Pacific Oceans. Two redfish management units encompass the eastern Scotian Shelf: Unit 3 covers NAFO Division 4WX, and Unit 2 includes NAFO Divisions 3Ps4Vs, 3Pn4Vn-June to Dec., 4Wfgj). Prior to 1993, redfish were managed as a larger management area (NAFO Div. 4VWX). The stocks consist of a mixture of *Sebastes mentella*, which is the predominant species, occurring in deep water basins and along the shelf edge and *S. fasciatus*, which occurs in deeper waters off the continental shelf. Differences between these species are not obvious, and therefore they are not separated by species in either the catch or the RV survey.

CATCH

Catch data were taken from NAFO and ZIF databases. Redfish are caught mainly by trawlers and catches of redfish were as high as 45,000 tons in the early 1970s before the extension of jurisdiction. Since then the average catch has declined and is below 10, 000 tons. In 1980-1985 the average catch was 6,425 t. which decreased to 2,454 t. in 1995-2000 (Table 21).

BIOMASS

Redfish are not sampled well by the RV survey because of their semi-pelagic habit and their distribution. Two sets of biomass estimates are available, the trawlable RV survey data and the q-adjusted biomass estimates (Table 21). Both follow the same general trend (Figure 9). Overall, since 1970, the biomass of redfish has had 3 cycles: high in the 1970s, followed by decrease, peaking at a lower level in the 1980s and generally low during the 1990s. The q-adjustment increases the biomass estimate of redfish by a factor of 14 in 1980-1985, from the trawlable biomass of 41,440 to 589, 201 t. These should be considered the extremes of the range of possible values. The high end of these values from the q-adjusted estimates was used as initial input values.

Table 21. Input parameter estimates for redfish.

	1980-1985	1995-2000
Catch, t.	6425	2602
Catch density, t·km^2	0.063	0.025
RV Biomass, t.	121881	22276
q-adjusted biomass, t.	589201	261502
Density (RV) t km^2	0.405	0.218
Density (q-adj). t km^2	5.758	2.556
P/B, yr^{-1}	0.242	0.222
Q/B, yr^{-1}	6.13	6.13

BIOMASS ACCUMULATION

There is no long-term increase or decrease in the biomass of redfish for either of the time periods. A short-lived increase in biomass during the early 1980s was not sustained, and there is no trend in the biomass during the late 1990s. Therefore no biomass accumulation term was entered for redfish.

PRODUCTION:BIOMASS

There are no direct estimates of production of redfish, but it is likely to be low because they have slow growth. Production is estimated here from the relationship $P=M*B+C$, assuming a natural mortality of 0.2 yr^{-1} (Table 21). Essentially, P/B is around 0.2 in both time periods.

CONSUMPTION:BIOMASS

Dolgov and Drevetnyak (1990) estimated annual food consumption to biomass ratios for Barents Sea deep-water redfish (*S. mentella*) to vary from 6 for fingerlings down to 1.3 for fish at age 19. An average for the whole populations was estimated as 2 yr^{-1} (Bundy et al. 2000). A Q/B of 6.13 yr^{-1} was estimated from the consumption analysis using redfish stomach data collected in 1999 and 2000 from the eastern Scotian Shelf. These values can be considered to bracket the range of possible values for Q/B. was used for both time periods since it is derived from the model area. The estimate from the eastern Scotian Shelf was used as input for both models, but may be too high.

DIET

There are no redfish diet data for the 1980-1985 time period from the eastern Scotian Shelf, so data from the western Scotian Shelf Scotian Shelf for the 1970s and 1980s was used (J. Link, NMFS, Pers. Comm). Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 137. The diet for the 1980-1985 was modified to include species seen in the diet for 1995-2000. See Table 15, Appendix 2 for further details.

16. POLLOCK

BACKGROUND

Pollock (*Pollachius virens*) are distributed from southern Labrador to Cape Hatteras, but are concentrated on the Scotian Shelf, Gulf of Maine and Georges Bank. Observations by fishermen and accoustic studies have shown that, of the gadoid species, they are the least demersal in habit, spend more time in the water column, and exhibit strong schooling behaviour. Young pollock are closely associated with nearshore habitats, and recruit to the offshore populations at around age 2. Since the nearshore is not included in the Ecopath models, the pollock group only includes the older offshore population. Pollock are managed as one unit across the Scotian Shelf, and the Canadian portion of Georges Bank and the Gulf of Maine (DFO 1999). Thus only a portion of the pollock population is included in the eastern Scotian Shelf area modelled with Ecopath.

CATCH

Pollock are caught primarily by otter trawl, but also by gillnets, handlines and longlines. Catch data were taken from NAFO and ZIF databases. Total catch was around 12,000 t during the 1960s, but fell at the end of this decade to a low in 1973, then steadily climbed to around 17,000 t in 1986. Since then it has decreased, and the catch in 1980-1985 is 10 times greater than the catch in 1995-2000 (Table 22).

BIOMASS

There are two biomass estimates available for pollock on the eastern Scotian Shelf, the trawlable biomass and the q-adjusted trawlable biomass (Table 22). Both had a broad peak in biomass over the 1980s, which has since declined (Figure 16). The q-adjusted biomass in 1980-1985 is twice the biomass in 1995-2000.

Table 22. Input parameter estimates for pollock

	1980-1985	1995-2000
Catch	12771	1324
Catch density	0.125	0.013
RV Biomass, t.	31000	8395
q-adjusted biomass, t.	99949	45203
Density (RV) t·km^2	0.303	0.082
Density (q-adj). t·km^2	0.977	0.442
P/B, yr^{-1}	0.311	0.306
Q/B, yr^{-1}	3.59	3.59

BIOMASS ACCUMULATION

There was no overall trend in biomass during the two time periods (Figure 10), thus no biomass accumulation term was used in the model.

PRODUCTION:BIOMASS

P/B was estimated from the SPA model for 4X/5 pollock (J. Nielson, DFO, pers. Comm.). Annual total production was estimated as the difference in biomass between year n and year n+1, plus losses due to fishing and losses due to other forms of mortality. P/B was estimated as total production divided by total SPA biomass producing a value of 0.311 yr^{-1} in 1980-1985 and 0.306 yr^{-1} in 1995-2000 (Table 22).

CONSUMPTION:BIOMASS

There were no consumption data available for the 1980-1985 time period. For the 1995-2000, a value of 3.59 yr^{-1} was estimated from the consumption analysis using pollock stomach data collected in 1999 and 2000 from the eastern Scotian Shelf (Table 22). Pauly (1989) estimated a Q/B of 4.76 yr^{-1} for pollock on George's Bank. Given the similarity on P/B values estimated for the two time periods, the Q/B may be expected to be similar too. The value estimated from the eastern Scotian Shelf was used for both time periods.

DIET

The 1980-1985 average diet of pollock was estimated from pollock stomachs collected on a pollock survey of the Scotian Shelf from 1983 to 1988 (Laurinolli et al. 2004). Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 137. The diet for the 1980-1985 was modified to include species seen in the diet for 1995-2000. See Table 16, Appendix 2 for further details.

17. TRANSIENT MACKEREL

BACKGROUND

There are two populations of Atlantic mackerel (*Scomber scombrus*) in the Atlantic, the northern and the southern populations. These two populations over-winter together, but spawn separately. The northern population over-winters on the edge of the continental shelf, from Sable Island on the eastern Scotian Shelf to south of Long Island (Mackay 1979). In Spring, these mackerel migrate across the Scotian Shelf to the Gulf of St

Lawrence to spawn. Large fish head the migration, first appearing in surface waters during May and early June. Mackerel prefer warm waters, and their migration routes are sensitive to water temperature. Once they have spawned, mackerel are voracious feeders. After feeding in the Gulf of St. Lawrence, they migrate back over the Scotian shelf to deep-water wintering grounds. Small mackerel stay on the Scotian shelf year round, in deeper, warmer waters during the winter and move inshore in the summer. Kulka and Stobo (1981) found that mackerel in the Sable Island area during November and December 1976 were mostly 0 and 1 year olds. This is also true for Emerald Bank and Browns Bank areas.

The mackerel are treated here as two groups: mature, transient mackerel that migrate across the Scotian Shelf to spawn in the Gulf of St. Lawrence; and juveniles who spend their first two years on the shelf. There are also some mackerel that spawn on the Scotian shelf, and these are included in the transient mackerel. Mackerel mature at around 2 years (2.16 years) and at a length of 28.4 cm (Gregoire et al. 1997). Thus the mature mackerel were considered as those fish 2 years or older, or greater than 29 cm. Small mackerel are 0 and 1 year olds, less than or equal to 29 cm in length.

The small mackerel were grouped with the small pelagics. There were several reasons for doing this. Firstly, we do not have biomass estimates for these fish. Secondly, they spend time in coastal waters (which are not included in the model area) and in deeper waters, and thus are not the model area for the whole year. Lastly, since the model area does not include the whole mackerel distribution, the dynamics of the population will be more affected by events outside the model area than inside the model area. Thus, joining the dynamics of the juveniles and adults would create a tightness in their relationship which probably does not exist.

CATCH

During the 1980s, mackerel were mostly caught inshore by small vessels operating gillnets and traps, while some mackerel were also caught as by-catch in the silver hake fishery further offshore. Catch data were taken from NAFO and ZIF databases. The annual mackerel catch varies from 730 to 1, 892 t during the years 1980-1985 and 120 to 1182 t. during 1995-2000. Most of this catch is taken inshore and is in theory outside the model area. However, since this catch is taken from the population modelled as migrating across the shelf, it is included in the total catch. The average catch in 1980-1985 was 1, 358 t (0.012 t·km^{-2}), and 485 t (0.005 t·km^{-2}) in 1995-2000 (Table 23).

BIOMASS

The average annual mackerel biomass on the eastern Scotian Shelf is estimated from the egg survey estimates of the spawning stock biomass in the Gulf of St. Lawrence from 1983-1985 (F. Gregoire, DFO, pers. comm.). The average biomass for 1983-1985 was 525, 267 t. Since this biomass is not resident on the eastern Scotian Shelf for the whole year, it is adjusted for the proportion of the year spent on the shelf. It is assumed that for each direction of the migration, each fish takes 3-weeks to pass over the eastern Scotian Shelf. This method assumes that all fish pass over the eastern Scotian Shelf during their migration. Many take an inshore route, as evidenced by the inshore fishery. However, both are included in the model because we do not know how mackerel are distributed between inshore and offshore.

This produces a biomass estimate of 60, 608 t, 0.592 t·km^{-2}. The lower and upper biomass limits of 0.395 and 0.790 tkm^2 were estimated by assuming that mackerel take 2 and 4 weeks respectively to pass over eastern Scotian Shelf. For 1995-2000, these values are 22, 728 t, 0.222 t·km^{-2}, with lower and upper limits of 0.142 and 0.285 t·km^{-2} (Table 23).

Table 23. Input parameter estimates for mackerel.

	1980-1985	1995-2000
Catch, t.	1358	485
Catch density, t·km^2	0.012	0.005
Biomass, t.	60, 608	22,728
Density (RV) t km^2	0.592	0.214
P/B, yr^{-1}	0.29	0.29
Q/B, yr^{-1}	2.2	2.2

BIOMASS ACCUMULATION

Although there has been a decrease in mackerel biomass from 1980-1985 to 1995-2000 there was no overall trend in biomass during the two time periods, thus no biomass accumulation term was used in the model.

PRODUCTION:BIOMASS

It is assumed that P/B = Z. Annual Z for the northern mackerel stock is between 0.2 and 0.3 (reference for this?), whilst a multispecies VPA estimated a Z of 0.29 yr-1 for North Sea mackerel (Christensen 1995a). In the absence of specific production estimates for the northern mackerel population, P/B is taken as 0.29 yr^{-1} for both time periods.

CONSUMPTION:BIOMASS

In the absence of consumption estimates for mackerel on the eastern Scotian Shelf, an estimate of 4.4 yr^{-1} for Georges Bank mackerel was used (Pauly 1989). This estimate is high, and since mackerel do not feed intensively while migrating (F. Gregoire, T. Lambert, DFO, pers comm.) this value was reduced by 50% to 2.2 yr^{-1}.

DIET

There are three sources of information on mackerel diet on the Scotian Shelf. Kulka and Stobo (1981) sampled the outer edge of the Scotian shelf during November and December 1976. Gregoire and Castonguay (1989) sampled mackerel from various locations, including Emerald Basin on the eastern Scotian Shelf during 1979-1980. MacKay (1979) sampled the inshore and offshore of the Scotian Shelf and the Gulf of St. Lawrence from May to October, 1965-1973. Data were recorded as % weight by Kulka and Stobo (1981), % occurrence and number by Gregoire and Castonguay (1989) and in a descriptive format by Mackay (1979). Table 17, Appendix 2.1 presents these data. Percent number was translated directly as % weight. The "+" were summed and each "+" was taken to represent that proportion of the sum. The final diet was taken as the average of the three diets and in the absence of data for 1995-2000, this was used for both time periods.

18, 19. LARGE AND SMALL DEMERSAL PISCIVORES

BACKGROUND

The demersal piscivores are a composite group comprising white hake (*Urophycis tenuis*), cusk (*Brosme brosme*), sea raven (*Hemitripterus americanus*) and monkfish (*Lophius americanusi)*. They are all demersal fish which are distinguished from the large demersal feeders described below because of their more piscivorous feeding habit. Their distribution ranges from the Grand Banks southwards as far as the mid-Atlantic Bight in the case of white hake and inhabit deeper waters.

The demersal piscivores were split into small and large demersal piscivores at 40 cm, which corresponds to the length of maturity of white hake and monkfish at age 3 (Fowler at al. 1996) and 3-4 (Armstrong et al. 1992) respectively.

CATCH

There are commercial fisheries for white hake, cusk and monkfish. Traditionally they had little commercial value and were caught as bycatch in other fisheries. It is likely that many were discarded and thus unrecorded. Since the early to mid-1990s have been subject restrictive bycatch quotas for conservation and stock re-building purposes. Catch data for white hake, monkfish and cusk were taken from NAFO and ZIF databases (Table 24). Catches of all species have decreased from 1980-1985 to 1995-2000. Catches have generally been low, with the exception of the 1970s when catches of monkfish averaged 10,000t between 1971 and 1975. It is assumed here that all the recorded catch of demersal piscivores is for fish > 40 cm, that is, large demersal piscivores.

Table 24. Average catch (t) of demersal piscivores, 1980-1985 and 1995-2000.

	1980-1985	1995-2000
White Hake	950	446
Monkfish	126	91
Cusk	399	180
Total catch	1475	716
Catch density, t·km^2	0.014	0.007

BIOMASS

The catchability adjusted biomass of large demersal piscivores has decreased by 75 % from 1980-1985 to 1995-2000 (Figure 11, Table 25). This decrease is seen for all species: white hake biomass increased during the 1980s, but since 1985 has steadily decreased and remained at around 3000 t since 1993; the biomass of monkfish, cusk and sea raven has decreased throughout the time period to the early 1990s, and has remained low. The biomass of the small demersal piscivores has decreased slightly from 1980-1985 to 1995-2000. The greatest biomass of small white hake was present in the early 1980s, and since then it has fluctuated, decreasing since 1997; small monkfish and sea raven have slowly increased since the early 1980s. Small cusk are rarely seen by the RV survey.

Table 25. q-adjusted biomass (t) estimated for small and large demersal piscivores

	1980-1985	1995-2000
Small white hake	7916	6066
Small cusk	41	0
Small monkfish	594	1149
Small searaven	226	725
Total biomass	8777	7941
Biomass density, t·km^2	0.086	0.078

	1980-1985	1995-2000
Large white hake	15241	3111
Large cusk	739	119
Large monkfish	3444	1320
Large searaven	907	381
Total biomass	20332	4932
Biomass density, t·km^2	0.199	0.048

BIOMASS ACCUMULATION

With the exception of white hake, there was no overall trend in biomass during the two time periods for either large or small demersal piscivores (Figure 11). Large and small white hake increased from 1980 to 1983, but this was not sustained. No biomass accumulation term was used in the model.

PRODUCTION:BIOMASS

There are no direct estimates of production for any of the demersal piscivores on the eastern Scotian Shelf. Production of the adults is estimated here from the relationship P=M*B+C, assuming a natural mortality of 0.2 yr^{-1} for each of the demersal piscivores species (Table 26). There is no recorded catch of sea raven, so its P/B cannot be estimated using this method. The P/B of monkfish is higher than for white hake or cusk. This is an artifact since in many years, the catch is greater than the estimated biomass. Thus monkfish biomass is underestimated, or monkfish catch is inaccurate, or both. For this reason, only white hake and cusk were used to estimate the average P/B for large demersal piscivores. There are no estimates of P/B for the juveniles so they are estimated from the Q/B ratio, assuming a P/Q of 0.15.

Table 26. Estimates of P/B and Q/B for large demersal piscivores, 1980-1985 and 1995-2000.

Parameter		1980-1985	1995-2000
P/B	White Hake	0.280	0.368
	Monkfish	0.638	0.883
	Cusk	0.323	0.359
	Average (excluding monkfish)	0.301	0.363
Q/B	Large demersal piscivores	4.22	4.22
	Small demersal piscivores	5.18	5.18

CONSUMPTION:BIOMASS

There are no estimates of consumption for the 1980-1985 time period. For the 1995-2000 time period, a value of 4.22 yr^{-1} and 5.18 was estimated for large and small white hake respectively, from the consumption analysis using white hake stomach data collected in 1999 and 2000 from the eastern Scotian Shelf (Table 26). A value of 3.1 was estimated for the Gulf of St. Lawrence (need ref and size range). These values may be considered to encapsulate the range of possible Q/B values. The values from the eastern Scotian Shelf for 1995-2000 were used for both time periods.

DIET

Large demersal piscivores diet

For the 1980-1985 diet, white hake diet data were available from the eastern Scotian Shelf from the pollock survey in 1984. Monkfish and sea raven diets were taken from NMFS surveys of George's Bank and the western Scotian Shelf (J. Link, NMFS, Pers. Comm). Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 97.

The diet for the 1980-1985 was modified to include species seen in the diet for 1995-2000. See Tables 18a and 18b, Appendix 2 for further details.

Small demersal piscivore

Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 273. For the 1980-1985 time period, there were only 14 small white hake stomachs collected during the Pollock Survey, but this is insufficient data to estimate an average diet Instead, the 1995-2000 diet was adapted for the 1980-1985 time period. See Table 19, Appendix 2 for further details.

20, 21. LARGE AND SMALL LARGE DEMERSAL FEEDERS

BACKGROUND

The large demersal feeders are a large composite group including: the eelpouts (Zoarcidae), arctic eelpout, Newfoundland eelpout, shorttailed eelpout, vachon's eelpout, wolf eelpout, laval's eelpout and ocean pout (*Macrozoarces americanus*),; grenadiers (Macouridae), rock grenadier (roundnose), roughnose grenadier, marlin-spike grenadier; hakes (*Urophycis sps.*) longfin hake, red hake; wolffish (Anarhichadidae) northern wolffish, striped atlantic wolffishand spotted wolffish; and lumpfish (*Cylopterus lumpus*). They are all demersal fish that are distinguished from the demersal piscivores described above because their diets are less piscivorous.

The large demersal feeders are split into large and small fish at length 30 cm, which corresponds to the length of maturity for red hake (Scott and Scott 1988). This should be representative of most of the species on this large group.

CATCH

There has been little targetted fishing for any of the large demersal feeders, although it is likely that many have been caught as bycatch in the past and subsequently discarded. Of the recorded catches, only wolffish and red hake have been caught in any amount (Table 27). Catch data for the large demersal feeders were taken from NAFO and ZIF databases. It is assumed here that all the recorded catch of large demersal feeders is for fish > 30 cm, that is, large demersal piscivores.

Table 27. Average catch (t) of large demersal feeders, 1980-1985 and 1995-2000.

	1980-1985	1995-2000
Wolffish	395	8
Red hake	289	164
Other	0	28
Total catch	684	201
Catch density, t·km^2	0.007	0.002

BIOMASS

Several of the large demersal feeders are either not sampled well by the RV trawl survey due to their distribution, behaviour or both. The northern wolffish for example is only seen sporadically through the 30 year time series, others are rarely seen. Few of the small large demersal feeders are sampled well with the RV survey. Even with adjustments for catchability, these estimates may under represent the actual biomass of these species.

Four species, longfin hake, red hake, wolffish and Vahls eelpout comprise over 90 % of the q-adjusted large demersal biomass over the length of the RV survey (1970-2002). Overall, the large demersal feeders biomass increased to a high of over 12,000t in 1984, but declined to 2000 t in 2002. However, this masks variation in the biomass trends of the individual species (Figure 12). Striped Atlantic wolffish and longfin hake have declined to a low level over the last 2 decades. Red hake biomass was low in the 1970s, high during the 1980s, dropping to a low in 1991, but since recovering to a level intermediate between the 1970s and 1980s. Vahl's eelpout increased from the mid-1980s to 1997, but has since decreased. The biomass of large demersal piscivores decreased by 50% from the 1980-1985 to 1995-2000.

Three species make up over 90 % of the q-adjusted small large demersal biomass, longfin hake, red hake and Vahl's eelpout. There was a large peak in the biomass of small longfin hake in 1984 and 1985, probably due to longfin hake coming on to the shelf due to temperature, current or other environmental effects. Otherwise, the biomass has been variable with no trend. Red hake is low, with little trend over the time series. Like the large Vahl's eelpout, the small Vahl's eelpout increased from the mid-1980s to 1997, but has since decreased. The biomass of small large demersal piscivores decreased by around 33 % from the 1980-1985 to 1995-2000.

Table 28. q-adjusted biomass (t) estimated for small and large large demersal feeders

Small Large demersal feeders

	1980-1985	1995-2000
Longfin hake	14110	6050
Red hake	1261	1144
Vahl's eelpout	116	2310
Other	240	574
Total Biomass	15728	10078
Biomass density	0.154	0.098

Large Large demersal feeders

	1980-1985	1995-2000
Longfin hake	1148	90
Red hake	3182	1506
Wolffish	2783	811
Vahl's eelpout	566	1432
Other	1270	558
Total Biomass	8949	4397
Biomass density	0.087	0.043

BIOMASS ACCUMULATION

There was no overall trend in biomass during the two time periods for either large or small large demersal feeders (Figure 12), thus no biomass accumulation term was used in the model.

PRODUCTION:BIOMASS

There are no direct estimates of production for any of the large demersal feeders on the eastern Scotian Shelf. Production of the adults is estimated here from the relationship $P=M*B+C$, assuming a natural mortality of 0.2 yr^{-1} for each of the large demersal feeders species (Table 29). Only red hake and wolffish have been caught in any quantity, so P/B is only estimated for these species. There are no estimates of P/B for the juveniles so it is assumed that they are twice the large estimates, rounded to the nearest one decimal place.

Table 29. Estimates of P/B and Q/B for large demersal feeders, 1980-1985 and 1995-2000.

Parameter		1980-1985	1995-2000
P/B yr^{-1}	Red Hake > 30 cm	0.355	0.212
	Wolffish > 30 cm	0.333	0.336
	Average (large)	0.344	0.274
	Small (2* large)	0.7	0.6
Q/B yr^{-1}	Large large demersal feeders		
	Small large demersal feeders		

CONSUMPTION:BIOMASS

There are no estimates of consumption for the 1980-1985 time period and the estimates for the 1995-2000 time period are poor. Q/B for both size groups is estimated from the P/B ratio, assuming a P/Q of 0.15. For the juveniles, the estimate of 4 agrees with the estimate of 4.02 yr^{-1} for small red hake (n=45) from the consumption studies from the eastern Scotian Shelf, giving some credence to the estimate.

DIET

Large large demersal feeders

For the 1980-1985 time period, there were no estimates of large demersal feeders diet directly from the eastern Scotian Shelf. However, wolffish data were available for the northwest Atlantic (diet estimated in Bundy et al. 2000), red hake and ocean pout data were available for George s Bank and the wss (Jason Link, NMFS, pers.comm), longfin hake diet was adapted from data in Bundy et al. (2000). These diets were used to estimate a biomass weighted diet for the large demersal feeders for 1980-1985. See Table 20a and 20 b, Appendix 2 for further details

Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of only 54.

Small large demersal feeders

Data for the 1995-2000 time period was estimated from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000, with a sample size of 132. For the

1980-1985 time period, there were no data available so the 1995-2000 diet was adapted for this time period. See Table 21, Appendix 2 for further details.

22. SMALL DEMERSALS

BACKGROUND

Small demersals are described as small (generally less than 30 cm) bottom dwelling fish that have benthic food preferences. There are over 26 species of small demersals on the eastern Scotian Shelf, but little is known about any of them. The most abundance is the longhorn sculpin, *Myoxocephalus octodecemspinosus*, which can account for over 90% of the total small demersal biomass. Other species in this group include, alligatorfish Arctic hookear sculpin, Atlantic sea poacher, Atlantic spiny lumpsucker, cunner, daubed shanny, fourbeard rockling, Altantic hookear sculpin, longnose greeneye, mailed sculpin, polar sculpin, radiated shanny, rosefish, seasnail, short-nose greeneye, slender eelblenny, snake blenny and wrymouth.

CATCH

There is no fishery for small demersals, but a small annual by-catch of 0.142 t. of sculpins was landed from 1995-2000.

BIOMASS

The RV trawlable and q-adjusted biomass for the more abundant small demersal species is shown in the table below.

Table 30. Small demersal biomass estimates (t) from the RV Survey (trawlable biomass) and adjusted for catchability averaged over 1980-1985 and 1995-2000.

	1980-1985		1995-2000	
	RV Biomass	q-adj Rv B	RV Biomass	q-adj RV B
Rosefish	1	97	49	1980
Mailed sculpin	25	152	94	720
Longhorn sculpin	1219	2963	3534	7349
Daubed shanny	< 1	1	24	323
Snake blenny	< 1	10	148	950
Other	26	98	130	827
Total	1271	3322	3979	12149
Biomass Density	0.012	0.032	0.039	0.119

BIOMASS ACCUMULATION

There was no overall trend in biomass during the two time periods for small demersal feeders, thus no biomass accumulation term was used in the model.

PRODUCTION:BIOMASS

In the absence of other data, it was assumed that the P:B ratio was in the range of 0.2 - 0.8 yr^{-1}. This puts total annual production in the range of 664 – 2657 t in 1980-1985 and 2430 – 9719 t. in 1995 – 2000, based on the q-adjusted biomass estimates. An initial input value of 0.5 yr^{-1} was used for both the 1980-1985 and 1995-2000 models.

CONSUMPTION:BIOMASS

The estimate of Q/B from the empirical stomach analysis for the 1995-2000 model is 4.27 yr^{-1} for longhorn sculpin (n=241), but there are no estimates of consumption for the other species represented by this group, or for the 1980-1985 time period. In the absence of other information, 4.27 yr^{-1} was used to represent the small demersals in both time periods.

DIET

There is very little diet data available for small demersals on the eastern Scotian Shelf. For the 1980-1985 time period, the diet from the Newfoundland-Labrador model, presented in Bundy et al. (2000) was used, together with diet data for longhorn sculpin from Georges Bank and the western Scotian Shelf for the 1980s (Table A.22a, Appendix 2.1). For 1995-2000, diet data for little studied fish, collected by Jeff Hutchings (Dalhousie University, *http://www.marinebiodiversity.ca/en/research-funded.html#ecology*) in 2000 and 2001 was used, together with longhorn sculpin diet data from stomach samples taken during the Spring and Summer RV surveys in 1999 and 2000 (Table 22b, Appendix 2)

23. CAPELIN

BACKGROUND

Capelin (*Mallotus villosus*) is a short-lived, pelagic species that is an important prey for many fish and marine mammal species. Its typical distribution is to the north of the eastern Scotian Shelf, centering on NAFO Divisions 2J3KL off Newfoundland Labrador. Since the late 1980s however, capelin have occurred in increasing abundance on the eastern Scotian Shelf, primarily in NAFO Division 4V. This extension of their distribution is thought to be a response to changing environmental conditions on the eastern Scotian Shelf, and in particular to a period of below normal temperatures (Frank et al. 1996). Since the late 1990s, their abundance has decreased, coincident with increasing water temperatures.

CATCH

There is no commercial catch of capelin on the eastern Scotian Shelf.

BIOMASS

The RV trawlable and q-adjusted biomass for capelin are shown in the table below. A catchability factor of 0.005 is used.

Table 31. Input estimates for small demersal feeders

	1980-1985	1995-2000
trawlable biomass (t)	14	1477
q-adjusted biomass (t)	2853	295412
q-adjusted biomass density ($t \cdot km^2$)	0.028	2.887
P/B (yr^{-1})	0.7	1.0
Q/B (yr^{-1})	4.7	6.68

BIOMASS ACCUMULATION

There was no overall trend in biomass during the two time periods for capelin, thus no biomass accumulation term was used in the model.

PRODUCTION:BIOMASS

There is no information on production or mortality of capelin on the eastern Scotian Shelf, so estimates from Newfoundland were used. Bundy et al. (2000) used a P/B ratio of 1.15 yr^{-1}, including fishing mortality. Given that there were very few capelin on the eastern Scotian Shelf in 1980-1985, it was assumed that production would be lower than this and a value of 0.7 yr^{-1} was used. For the 1995-2000 model, a gross efficiency of 0.15 was assumed, and P/B estimated from the Q/B estimate (see below) producing a P/B ratio of 1.0 yr^{-1} (Table 31). This higher value for the 1990s makes sense since capelin were much more productive in the 1990s.

CONSUMPTION:BIOMASS

The estimate of Q/B from the empirical stomach analysis for the 1995-2000 model is 6.88 yr^{-1}, but there are no estimates of consumption for capelin for the 1980-1985 time period. Estimates of consumption to biomass ratios for capelin from Newfoundland ranged from 4.3 yr^{-1} to 8.5 yr^{-1} (Bundy et al. 2000). Assuming a gross efficiency of 0.15 for the 1980s results in a Q/B ratio of 4.7, which is within the range of estimates from Newfoundland (Table 31).

DIET

There are no diet data for capelin for the 1980s, so the diet from the Newfoundland-Labradror model presented in Bundy et al. (2000) was used (Appendix 2, Table 12). For the 1995-2000 model, diet estimates from the eastern Scotian Shelf were available (Table 23, Appendix 2). The two diets are similar, although the diet from the eastern Scotian Shelf contained shrimp and polychaetes which were not recorded in the Newfoundland diet.

24. SANDLANCE

BACKGROUND

The sand lance species group is assumed to be all northern sand lance (*Ammodytes dubius*). Its geographic range extends from West Greenland to Cape Hatteras in the USA. They are small, semi-demersal fish and are abundant in areas where the bottom substrate consists of sand and fine gravel where they burrow. They feed pelagically and are similar to capelin in their role as a forage species (Winters 1983). Since the late 1980s, the abundance of sand lance has increased greatly on the eastern Scotian Shelf.

CATCH

There is no commercial catch of sand lance on the eastern Scotian Shelf.

BIOMASS

The biomass of sand lance has increased dramatically on the eastern Scotian Shelf since the late 1980s. In 1980-1985 the average trawlable biomass was 54 t., whereas in 1995-2000 it was 11, 452 t., an increase of over 200 fold. Unlike capelin, sand lance has always been present in the RV surveys of the eastern Scotian Shelf, although catches have been spotty over the years (Figure 13). The catchability of sand lance to the RV survey on the eastern Scotian Shelf is not known, but it is likely to be very low due to the small size of the fish and their burrowing habit. There is a range of catchability estimates in the literature (Harley et al. 2001), which are applied to the sand lance trawlable biomass in Table 32.

The range of biomass estimates is clearly very wide. Estimates of sand lance density of 128 t·km^2 and 464 t·km^2 for the 1995-2000 model are too high. An alternative approach to estimating sand lance biomass is to explore what has been found elsewhere. Hoines and Bergstad (2001) estimated sand lance density off the coast of Norway and on a fishing ground in the North Sea. They estimated a mean density of 60.9 fish m^2 on an off shore bank, with a range of 0 to 290 fish m^2 and a model density of 10 fish m^2. If it is assumed that these densities may be similar to those that are now seen on the eastern Scotian Shelf, they can be used to calibrate the catchability estimates.

The average weight of a sand lance in the RV survey from 1990 to 2002 was 21.05 g. Thus the modal density estimated above in numbers of fish equates to 210.5 t·km^2. Since these densities apply only to areas where sand lance are found, this number needs to be adjusted to represent the average over the whole of the eastern Scotian Shelf. Sand lance occupy approximately 10% of the shelf area. The final estimate of sand lance density is thus approximately 21.05 t·km^2. Assuming a catchability of 0.005 would produce an estimate of 22.38 t·km^2 of sand lance for 1995-2000. Assuming the same catchability in 1980-1985 gives an estimate of 0.105 t·km^{-2} for the 1980-1985 model.

Table 32. Estimates of sand lance biomass using different assumptions about catchability

	Catchability	Biomass (t)		Density (t·km^2)	
		1980-1985	1995-2000	1980-1985	1995-2000
Trawlable biomass	1	54	11452	0.0005	0.11
Edwards	0.0153	3519	748507	0.0344	7.31
English Groundfish Survey	0.00087	61895	13163395	0.6049	128.64
International Young Fish Survey	0.000241	223437	47519309	2.1836	464.40
Estimated catchability	0.005	10770	2290431	0.1052	22.38

There is a lot of uncertainty associated with these estimates of sand lance biomass. For the 1980-1985 model, a range of 3,519 to 10,770 t (0.03 – 0.1 t·km^2) was used and for the 1995-2000 model, 748,507 to 2,290,431 t (7.31 to 22.38 t·km^2). These ranges represent the lower and upper bounds of what may be considered reasonable, given the Hoines and Bergstad (2001) study.

BIOMASS ACCUMULATION

There was no biomass accumulation of sand lance during 1980-1985. The biomass of sand lance increased greatly during the 1990s, but due to the uncertainty associated with the estimation of biomass, no biomass accumulation term was entered for 1995-2000.

However, it should be noted that given the large increase in biomass, production is greater than mortality during this period.

PRODUCTION:BIOMASS

There are no estimates of P/B for sand lance on the eastern Scotian Shelf. However, Winters (1983) estimated the average instantaneous total mortality rate (Z) of sand lance on the Grand Banks using catch curve analysis based on catches during research vessel surveys. In 1975-1979, when the biomass of cod was approximately 100,000 t, Z was 0.62 yr-1 whereas in 1968-1974 when cod biomass was approximately 500,000 t, Z was estimated as 1.15 yr^{-1}. It is thought that cod predation on sand lance is a major contributor to sand lance mortality and variability in abundance in Newfoundland waters (Winters 1983) and this is also likely to be the case on the eastern Scotian Shelf. Cod biomass was high in the 1980-1985 time period, prior to the cod collapse and it is assumed that mortality on sand lance was also high and that the Z estimate of 1.15 yr^{-1} is applicable. Conversely, cod biomass is very low in the 1995-2000 period and it is thus assumed that Z=0.62. Given the assumption that P/B=Z (Allen 1971) the P/B given in the Table 33 below apply.

Table 33. Sand lance estimates of P/B and Q/B for the 1980-1985 and 1995-2000 Ecopath models.

Parameter	1980-1985	1995-2000
P/B yr^{-1}	1.15	0.62
Q/B yr^{-1}	7.67	4.07

CONSUMPTION:BIOMASS

The Q/B ratio for the 1980-1985 period was estimated by assuming a gross efficiency of 0.15, producing a Q/B of 7.67 yr^{-1}. For the 1995-2000 time period, the estimate of sand lance Q/B 4.07 yr^{-1} from the stomach analyses was used.

DIET

There was no sand lance diet data for the 1980-1985 time period, so the diet used in Bundy et al. (2000) for the Newfoundland Labrador model was used (Appendix 2, Table 13). For the 1995-2000, diet estimated from the stomach analyses for 1999-2000 from the eastern Scotian Shelf was used, Table 24, Appendix 2.

25. TRANSIENT PELAGICS

BACKGROUND

The transient pelagics are a composite group of migratory species that are seasonally present in the Spring/Summer on the eastern Scotian Shelf. The main species are sharks (including porbeagle (*Lamna nasus*), basking shark (*Cetorhinus maximus*) and blue shark (*Requin bleu*), swordfish (*Xiphias gladus*), tuna (bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*T. albacares*), albacore tuna (*T. albacares*) and offshore hake (*Merluccius albidus)* which is present year round, but is mostly off the shelf in deep water.

CATCH

Catch data were taken from NAFO and ZIF databases. A significant portion of the catch of swordfish, tuna and sharks that are caught in NAFO Divisions 4VsW are fished in deep waters off the shelf edge that are not included in the model. The catch data from the NAFO and ZIF databases were adjusted to include only those fish extracted from the model area. The catch data in the NAFO database is only available at the NAFO Division and subdivision level. However, the ZIF catch data (1986-2000) is available at the unit level: some units are clearly on or off the shelf whereas others straddle the shelf edge. It was assumed that 50% of the catch from these areas were caught from the model area. The proportion of the catch in the model area to total catch from the ZIF database was used to prorate the catch from the NAFO database for the 1980-1985 time period (Table 34).

Table 34. Catch estimates for transient pelagics.

	1980-1985	1995-2000
Tunas	1	86
Swordfish	174	472
Sharks	16	466
Total	192	1025
Catch density (t·km^{-2})	0.002	0.010

Discarding

Bycatch of porbeagle shark in the Canadian swordfish and Japanese tuna longline fisheries and various in shore fisheries in minimal, rarely exceeding 40 tons per anum in recent years (DFO 2001b). Bycatch of blue sharks across NAFO Divs 2-5 has been estimated (Campana et al. 2002) and is high. Unfortunately, these data are not presented on a Divisional basis, but given than most of the bycatch occurs in the swordfish fishery, which is mostly offshore (outside the model area), the bycatch from the shelf area is likely to average around 85 tons per year during 1995-2000 (estimated from Figures 5-13, Campana et al. 2002).

BIOMASS

The RV survey does not sample many of the transient pelagics, so the total biomass cannot be estimated from this source.

Offshore hake

The biomass for this group was estimated from the RV survey.

Swordfish

The estimated biomass of swordfish in the North Atlantic has decreased since the mid 1970s. It was around 100,000 tons in 1980-1985 and 60,000 tons in 1995-2000 (ICCAT 2003). In order to estimate biomass, this estimate was pro-rated for the model area based on the ratio of the catch in the model area to the total catch of swordfish in the North Atlantic. The biomass of swordfish was estimated by applying a mean exploitation rate of 7 % to the catch from the model area for both time periods.

Sharks

There are no estimates of shark biomass for the Northwest Atlantic. Baum et al. (2003) have shown that the relative abundance of several shark species, including blue shark, have decreased since the mid 1980s. Since the shark species on the eastern Scotian Shelf are part of a larger population, they are also likely to have decreased.

Tunas

No biomass estimates were available for this group. Given the low level of the catch, it is assumed that the biomass is also low. Given the level of uncertainty with the estimates presented here, the biomass of tunas is probably captured.

There are only biomass estimates for two of the transient pelagics (Table 35). In order to obtain an estimate of total biomass, the figures below were arbitrarily doubled.

Table 35. Biomass estimates (t) for the transient pelagics.

	1980-1985	1995-2000
Offshore hake	306	64
Swordfish	622	373
Sharks		
Tunas		
Total	928	473
Double estimates	1856	946
Density, t·km^2	0.018	0.009

BIOMASS ACCUMULATION

There is insufficient data to determine whether there is any biomass accumulation.

PRODUCTION:BIOMASS

There are no direct estimates of P/B for the transient pelagics on the eastern Scotian Shelf. Polovina (1996) estimated 0.2 yr^{-1} for blue shark. A P/B of 0.28 yr^{-1} was estimated for swordfish in the North Atlantic assuming P=M*B+C with an M=0.1. The average of these two estimates was used to represent the transient pelagics for both time periods.

Table 36. Estimate of P/B and Q/B for transient pelagics

Parameter		Both models
P/B	Blue shark	0.2
	Swordfish	0.28
	Average	0.24
Q/B	Basking shark	3.7
	Swordfish	4.6
	Bluefin tuna	3.9
	Average	4.07

CONSUMPTION:BIOMASS

There are no direct estimates of Q/B for the transient pelagics on the eastern Scotian Shelf, but there are some estimates from other areas. Pauly (1989) gives an estimate of 3.7 yr^{-1} for basking shark from the North Sea, Stillwell and Kohler (1985) estimated a range of 3.4 to 5.8 for swordfish (average = 4.6) and a Q/B of 3.9 for bluefin tuna was reported from Japan (Palomares and Pauly 1989). The average of these values, 4 yr^{-1}, is used for both time periods (Table 36).

DIET

There were no diet data for the transient pelagics for the eastern Scotian Shelf specifically, but there were data for swordfish from Newfoundland, southwest Nova Scotia, George's Bank and Cape Hatteras (Laurinolli et al. 2004). Diet data for blue shark was available from Georges Bank from 1972-1980 (Kohler and Stillwell 1981). These diets were averaged to give an average diet for the transient pelagics for both time periods. See Table 25, Appendix 2 for further details.

26. SMALL PELAGICS

BACKGROUND

The small pelagics group includes herring (*Clupea harengus harengus*), Atlantic argentine (*Argentina silus*), American shad (*Alosa sapidissima*), Alewife (*Alosa pseudoharengus*), butterfish (*Poronotus triacanthus*) and the juveniles of Atlantic mackerel (*Scomber scombrus*), < 29 cm (see Transient mackerel above). Several of these species are transient residents of the eastern Scotian Shelf and occupy different areas of the shelf.

The main herring population is the Scotian Shelf herring spawning component of the 4VWX herring stock. This may be a separate spawning component with spawning occurring in mid to late October to early November in the Sable Island Bank and Western Bank area (Harris and Stephenson 1999). The southwest Nova Scotia/Bay of Fundy spawning component overwinters in Chedabucto Bay, which is inshore of the area of the model. Some fish may migrate through the model area enroute from southwest Nova Scotia. The coastal Nova Scotia Spawning component is also inshore of the model area. Abundance of herring, like sand lance, on the eastern Scotian Shelf has increased greatly since the late 1980s.

The argentine is a deeper water, slow growing fish, a member of the upper continental slope fauna. It has been regularly caught in RV trawl survey gear since the beginning of the time series (1970) but since 1996 has been less abundant. American shad and alewife are anadramous species and occur sporadically in the RV survey. Butterfish are not abundant on the eastern Scotian Shelf, but are regularly caught in the RV survey.

CATCH

Herring are the only species that has a targeted fishery in the model area. A foreign fishery for herring occurred on the offshore banks of Nova Scotia until the extension of jurisdiction in 1977, taking between 600 to 60,000 tons in a single year (Harris and

Stephenson 1999). After this, the fishery ceased, but was reinitiated in 1996 in response to evidence of a growing abundance of herring and of spawning offshore. It is assumed that the herring caught from 4VsW in the 1980-1985 time period were from the southwest Nova Scotia/Bay of Fundy spawning component that overwinters in Chedabucto Bay. The catch from the 1995-2000 period refers only to herring caught offshore. Argentine are caught mainly as a bycatch in the silver hake and redfish fisheries, while American Shad are caught mainly as a bycatch in the silver hake and pollock fisheries. Alewife are caught inshore and are thus not included in the catch estimate. The total catch for each time period is given in Table 37.

Table 37. Average annual catch of small pelagics from the eastern Scotian Shelf.

	1980-1985	1995-2000
Alewife	28.7	39.0
American Shad	1.5	0.2
Atlantic Argentines	336.7	17.9
Atlantic Herring		2598
Others	4.3	2.2
Total Catch	371.2	2657.0
Density	0.00363	0.02597

BIOMASS

The average trawlable biomass of herring has increased from 1,059 t. in 1980-1985 to 42, 750 t, in 1995-2000, an increase of 40 fold (Figure 14). Argentine biomass has decreased, and the biomass of the other species is too spotty to determine a trend. Small pelagic fish are not well sampled by the RV groundfish survey. However, in order to estimate their biomass, a catchability adjustment biomass was estimated (Table 38), using a catchability of 0.025 from the English Groundfish Survey (Harley et al. 2001).

Table 38. Estimates of small pelagics biomass assuming a catchability of 0.025.

	Trawlable Biomass, t.		Catchability Adjusted Biomass, t.		Density $t \cdot km^2$	
	1980-1985	1995-2000	1980-1985	1995-2000	1980-1985	1995-2000
Herring	1059	42750	42698	1723808	0.417	16.846
Argentine	1673	437	67461	17609	0.659	0.172
American shad	29	13	1180	519	0.012	0.005
Butterfish	151	193	6095	7778	0.060	0.076
Alewife	13	3	523	123	0.005	0.001
	2925	43396	117956	1749836	1.15	17.10

BIOMASS ACCUMULATION

There was no biomass accumulation of sand lance during 1980-1985. The biomass of the small pelagics increased greatly during the 1990s, but due to the uncertainty associated with the estimation of biomass, no biomass accumulation term was entered for 1995-2000. However, it should be noted that given the large increase in biomass, production is greater than mortality during this period.

PRODUCTION:BIOMASS

There is no information for production of herring or the other small pelagics on the eastern Scotian Shelf. SPA data for the southwest Nova Scotia/Bay of Fundy spawning component were used to estimate the total production of herring. This was estimated as the difference in biomass between year n and year n+1, plus losses due to fishing and losses due to other forms of mortality. P/B was estimated as total production divided by total SPA biomass. The estimates for 1980-1985 and 1995-1998 are given in Table 39. Data for 1999 and 2000 were not available.

CONSUMPTION:BIOMASS

There are no direct consumption estimates for small pelagics from the eastern Scotian Shelf. Pauly (1989) estimated a Q/B of 4.59 yr^{-1} for herring on George's Bank. In the absence of other information, this value was used here for both time periods.

Table 39. Estimates of P/B and Q/B for small pelagics for the 1980-1985 and 1995-2000 Ecopath models.

	1980-1985	1995-2000
P/B yr^{-1}	0.514	0.468
Q/B yr^{-1}	4.59	4.59
GE	0.11	0.10

Diet

There are no diet data for small pelagics from the eastern Scotian Shelf. Diet data for two other areas were available, George's Bank (1990-1998) and from the Gulf of St. Lawrence and adjacent areas (1970-1973), Messieh et al. (1979), as interpreted by Bundy et al. (2000, (Appendix 2, Table 17). The two diets are very similar, as shown in Table 26, Appendix 2. In the absence of other data, the same diet was used for both time periods and was based on the Messieh diet, with shrimp added, as in the Georges Bank diet.

27. SMALL MESOPELAGICS

BACKGROUND

Small mesopelagics are deepwater species such as the lanternfishes (Myctophidae) and hatchetfishes (Sternoptychidae). This group is poorly known and rarely caught in the research vessel surveys. They occur in deep water around and off the shelf edge. Many make diurnal vertical migrations, ascending to depth 30-100 m from the surface at night from depths from 300-1200 m (Scott and Scott 1988).

BIOMASS

There are no biomass estimates of small mesopelagics available from the RV survey and this their biomass was estimated by the model, by assuming a default ecotrophic efficiency of 0.95.

BIOMASS ACCUMULATION

There is no information on changes of biomass of the mesopelagics.

PRODUCTION:BIOMASS

In the absence of other information, the value of 1.4 yr^{-1} used by Heymans and Pitcher (2002) was used.

CONSUMPTION:BIOMASS

In the absence of other information, the value of 4.8 yr^{-1} used by Heymans and Pitcher (2002) was used.

DIET

There were no diet data available for mesopelagics from the eastern Scotian Shelf. Diet data were adapted from those presented in Lilly (MS) for Newfoundland, see Table 27, Appendix 2.

28. SQUID

BACKGROUND

Squid are a composite group of all squid found on the Scotian shelf. The main species is the short-finned squid (*Illex illecebrosus*), which is highly migratory and spends only part of the year within the study area. Their distribution ranges from south of Cape Hatteras to Florida, where they are thought to spawn in late Autumn and early winter (Rowell et al. 1985a) to the Grand Banks of Newfoundland. The egg masses, larvae and small are transported north by the Gulf Stream and juveniles arrive on the Scotian Shelf in Spring where they feed intensively. They are distributed across the shelf and in the deeper waters off the edge of the shelf. The males mature before the females and leave during the Fall, for the spawning grounds to the south (Black et al. 1987) in advance of the females. Their life span is believed to be 1 to 1.5 years. Other squid species found on the eastern Scotian Shelf include the long-finned squid *Loligo pealei*.

CATCH

There was a very intensive fishery for short-finned squid in the mid to late 1970s when squid were very abundant. Since then, the catch has been very low (Figure 15). In 1980, the catch was 17, 091 t., then decreased to 9,935 t., then 1,182 t. in 1982. From 1983 to 1985 the average catch was 322 t. Thus the catch (and biomass) distribution over the 1980-1985 time period is very skewed. Based on catch distribution plots (Hatanata and Sako 1980), at least 50 % of the catch was taken off the shelf edge, out of the model area in the 1980-1985 time period. In the 1995-2000, most of the squid were taken as a by-catch in the silver hake fishery, and is thus assumed to be removals from the shelf.

Table 40. Average catch of short-finned squid 1980-1985 and 1995-2000.

	1980-1985	1995-2000
Catch (t)	4862	863
Adjusted Catch	2431	863
Catch density ($t \cdot km^2$)	0.024	0.008

BIOMASS

During the early 1980s, specific squid surveys were conducted in order to estimate squid biomass on the Scotian Shelf (Rowell et al. 1985b). These data were used to estimate squid biomass for the 1980-1985 time period for those strata on the eastern Scotian Shelf. The biomass from this survey is twice the biomass from the RV survey, indicating that the catchability of squid to the RV trawl survey is at most 0.5. For the 1995-2000 time period no such specialised surveys exist, so the catchability adjustment of 0.5 was applied to the RV survey data for these years. Since squid are only present on the shelf for half the year, these estimates were decreased by 50 % (Table 41) to represent their seasonal occupancy.

Table 41. Biomass estimates of short-finned squid on the eastern Scotian Shelf.

	1980-1985	1995-2000
Squid Survey (t)	15458	
RV Survey (t)	7098	4068
Adjusted RV Survey	14196	8137
Density (t·km^2)	0.076	0.040

BIOMASS ACCUMULATION

No biomass accumulation terms was entered for squid.

PRODUCTION:BIOMASS

The P/B ratio was estimated by assuming a gross efficiency of 0.15 for both time periods.

CONSUMPTION:BIOMASS

The Q/B ratio was taken from estimates of consumption and Q/B for the Gulf of Maine to Cape Hatteras for 1979 and 1980 (Maurer and Bowman 1985, Table 7). The average Q/B for Spring, Summer and Autumn over the two years was 4.45 yr^{-1}. This estimate was used for both time periods.

DIET

The diet of short-finned squid was taken from a feeding study from the Scotian Shelf and Georges Bank in 1974-1975 (Vinogradov and Noskov 1979, Table 4, and Armatunga 1980). The diet data in Armatunga are expressed qualitatively and are used to give further detail of the Vinogradov and Noskov data. Further details are given in Table 28, Appendix 2. It should be noted that only diet data for short-finned squid squid are used to represent the squid group. Armatunga (1980) noted that the fish component of the short-finned squid diet is relatively unimportant on the Scotian Shelf.

29, 30 CRABS

BACKGROUND

Crabs are split into two size groups, large crabs with a carapace width (CW) > 95 mm and small crabs with CW ≤ 95 mm. Large crabs are crabs with a carapace width > 95 mm, and are essentially snow crab (*Chinonecetes opilio*), red crabs (*Chaecon quinquedens*) and Jonah crabs (*Cancer borealis*). Small crabs include the juveniles of the large crabs plus smaller crabs species such as the toad crab (*Hyas araneus*), Arctic lyre crab (*Hyas coarctatus*) and rock crab (*Cancer irroratus*). The size split of CW=95mm was used since this is the minimum legal landing size of snow crab.

Of these crab species, snow crab is the main commercial species, accounting for 95% of the crab catch on the eastern Scotian Shelf since 1986. Snow crab are at the southern limit of their distribution on the eastern Scotian Shelf. Their landings and catch rates have increased steadily since the late 1980s, which may due to increase survival of early life history stages due to lower temperatures and decreased predation from groundfish (Tremblay 1997).

CATCH

The average catch of large and small crabs in 1980-1985 and 1995-2000 is estimated from NAFO and DFO ZIF statistics (Table 42).

Table 42. Catch of large and small crabs, $t\cdot km^2$.

	Catch (t)		Catch density ($t\cdot km^{-2}$)	
	1980-1985	1995-2000	1980-1985	1995-2000
Large Crab	95.3	3557	0.001	0.035
Small Crab	0	59	0	0.001

BIOMASS

Since 1997 there has been a dedicated survey on the eastern Scotian Shelf to estimate the biomass of snow crab (Biron et al. 2001). The biomass of snow crab in the 1980-1985 period was estimated by a regression of catch rate for 1997 to 1999 from Area 23 on biomass for Area 23 (1997-2000), and applying the regression equation to the years 1980-1985. A biomass of 0.15 $t\cdot km^{-2}$ was estimated for large crabs in 1980-1985 and 0.308 $t\cdot km^{-2}$ and 3.78 $t\cdot km^{-2}$ for large and small crabs respectively in 1995-2000.

BIOMASS ACCUMULATION

Due to the lack of biomass data until 1997, it was not possible to estimate a biomass accumulation term.

PRODUCTION:BIOMASS

The P/B ratio was estimated from an empirical formula developed by Brey (1995, 1999), to estimate annual somatic production/biomass ratio of benthic invertebrate populations. Eleven 11 parameters are used in a multiple linear regression (version 2.0), including mean weight, bottom water temperature (°C) and water depth (m). The P/B ratio for large crabs is 1.59 and for small crabs is 2.45-3.12. A value of 0.3 was used for the small crabs. The same values were used for both time periods.

CONSUMPTION:BIOMASS

Based on estimates of crab consumption from the baie–des–Chaleurs and the Gulf of St Lawrence (Brêthes et al. 1984) and a study by Thompson and Hawryluk (1990), it was assumed that the Q/B ratio for large crabs is 1.2 yr^{-1} and for small crabs is 1.5 yr^{-1} for both time periods.

DIET

There are no crab diet data from the eastern Scotian Shelf, so the diet of crabs was taken from a study by Brêthes et al. (1984) in the southwest Gulf of St. Lawrence, off the Gaspe Peninisula. See Table 29, Appendix 2 for further details.

31. SHRIMP

BACKGROUND

There are many species of shrimp on the eastern Scotian Shelf, including the northern shrimp *Pandalus borealis*, which is fished commercially, and other species such as *Pandalus montagui, Pasiphaea sp., Crangon sp., Spirontocaris sp., Eualus sp., Sabinea sp., Argis Sp., Lebbeus sp.,* and *Sclerocrangon Sp.* None of these species are fished commercially or are well described on the eastern Scotian Shelf. The parameters below are based on northern shrimp data for lack of other information. Like several other species on the eastern Scotian Shelf such as capelin, snow crab, sand lance and herring, the abundance of Northern shrimp has increased since the late 1980s. It occurs mostly on the eastern side of the eastern Scotian Shelf, in NAFO Division 4Vs. The distribution of the other shrimp species is not known.

CATCH

The average catch of shrimp has increased from 277 t in 1980-1985 to 3514 t in 1995-2000 is estimated from Marine Fish Division ZIF statistics and Koeller et al. 2003. These values do not include shrimp catches from Shrimp Area 13, which is in NAFO Division 4Vn. These catches are equivalent to 0.0027 t·km^2 and 0.034 t·km^2.

BIOMASS

Biomass estimates are only available for *P. borealis* but there is no clear idea regarding the abundance or distribution of the other shrimp species on the eastern Scotian Shelf. Estimates of *P. borealis* biomass were available from two survey series, DFO research cruises from 1978 to 1985 (Etter and Mohn 1988) and DFO Industry Shrimp Survey 1995-present (Koeller et al. 2003). The estimates in Table 43 do not include Shrimp Area 13. An arbitrary additional 25% biomass is added to the estimate to account for the unknown biomass of other shrimp species. This is likely to be an underestimate.

Table 43. Estimates of northern shrimp biomass from DFO and DFO-Industry research surveys.

	1980-1985	1995-2000
P. borealis	8366	16449
+ 25% for other species	2092	4112
	10458	20561
Density	0.102	0.201

BIOMASS ACCUMULATION

No biomass accumulation terms was entered for shrimp.

PRODUCTION:BIOMASS

There are no direct estimates of P/B available. An estimate of 1.7 yr^{-1} was derived from a population model developed by P. Koeller (DFO), varying natural mortality between 0.5 and 0.8. The standard deviation is 0.96. Another estimate of the P/B ratio was from an empirical formula developed by Brey (1995, 1999), see above. Using an average weight of 9.35 g, the P/B ratio is around 0.3.

This is a large disparity between these estimates. Since natural mortality is considered to be at least 0.5 yr^{-1}, the estimate derived from the Brey formulation appears incorrect. In the absence of other information, a P/B of 1.y yr^{-1} was used for both time periods, noting that this is an approximation.

CONSUMPTION:BIOMASS

In the absence of other information, it was assumed that the P/Q ratio is 0.15 on both time periods.

DIET

There was no diet information for shrimp on the eastern Scotian Shelf. Instead, the diet that was used by Bundy et al. (2000) for the Newfoundland-Labrador shelf was used here for both time periods (Table 30, Appendix 2).

32-35 BENTHIC INVERTEBRATES

BACKGROUND

The benthic invertebrates are treated as four groups: 32. Echinoderms, 33. Bivalve Molluscs, 34. Polychaetes and Other Benthic Invertebrates (OBI). The other benthic invertebrates include miscellaneous crustaceans, nematodes, other molluscs, and other meiofauna. These groupings reflect the major taxa observed on the Scotian Shelf (Stewart et al. 2001, Wildish 1984). The most recent comprehensive source of information on the benthos is a synthesis of marine benthic macrofaunal biomass and productivity by Stewart et al. (2001). Breeze et al. (2002) give a good synopsis on knowledge of benthic invertebrates on the eastern Scotian Shelf. It should be stressed however that benthic data are poor, and several assumptions are made in order to obtain model parameter estimates.

The shells of bivalves and echinoderms comprise a significant proportion of their body mass and are composed of inorganic matter that does not get transferred through the foodweb. Since the energy unit used in the Ecopath with Ecosim model is wet weight (t·km2), the model does not differentiate between shell and tissue weight and thus treats both as energy. Thus including shell weight in the estimate of body mass would result in a larger flow of energy to the next trophic level, or to the catch, than actually exists. In order to represent the transfer of the organic matter of the benthic groups more accurately, the catch and biomass estimates of bivalves and echinoderms were adjusted for the ratio of whole weight to organic weight. For echinoderms, a value of 0.6 was used (Laurinolli et al. 2004).

In order to calculate a conversion from total weight of bivalves to viscera weight, all bivalves caught during the 2001 summer research vessel survey on the eastern Scotian Shelf were collected measured and weighed. The length, width, and height in centimetres and the whole weight, shell weight, and meat weight in grams were recorded. A general conversion rate was then calculated based on all bivalves combined. The resulting conversion viscera weight=0.421 *total weight (used (Laurinolli et al. 2004). Note that these conversion factors are not the same as those used in the commercial fishery because here the interest is in the total organic weight of the animal whereas the fishery is only interested in the organic matter that is marketable (i.e. the muscle).

CATCH

Bivalve molluscs and echinoderms are the only benthic groups for which there is a commercial fishery. Catches by both fisheries have increased during the 1990s. Several species of bivalves are caught, with the main species being Scallops and Stimpsons Surf Clam (Table 44). The catch data adjusted to remove the shell weight are given in Table 45.

Table 44. Catch of benthic invertebrates, whole weight (tons).

	Bivalve scallops			Echinoderms	
	Scallops	Stimpson Surf Clam	Other Bivalves	Sea Urchins	Total
1980-1985	1025	0	177	0	1203
1995-2000	2195	16666	608	599	19469

Table 45. Catch of benthic invertebrates, organic weight (tons).

	Bivalve scallops					Echinoderms	
	Scallops	Stimpson Surf Clam	Other Bivalves	Total	Density $t\cdot km^2$	Sea Urchins	Density $t\cdot km^2$
1980-1985	432	0	75	506	0.005	0	0
1995-2000	924	7016	256	8197	0.080	240	0.002

BIOMASS

The biomass of the benthos groups was estimated in a very approximate way from the database of marine benthic macrofauna (Stewart et al. 2001). All records for the eastern Scotian Shelf were extracted from the database over all years, and a simple average was taken over all stations (Table 46). It had originally been hoped to estimate eastern Scotian Shelf biomass for the benthic groups in a more systematic fashion by correlating benthos groups with sediment type and depth. However, this was not considered feasible due to data limitations (P. Stewart, pers. Comm).

Table 46. Estimates of benthic biomass (density), P/B, Q/B and P/Q for the eastern Scotian Shelf.

Benthic Group	Density ($t\cdot km^2$)	P/B (yr^{-1})	Production (tkm^{-2})	P/Q	Q/B (yr^{-1})	Consumption (tkm^{-2})
32. Echinoderms	63.7	0.6	38.2	0.09	6.7	449
33. Polychaetes	11.9	2.0	23.8	0.09	22.2	356
34. Mollusca[1]	57.4	0.7	40.2	0.09	7.8	460
35. Other Benthic Invertebrates	4.9	2.5	12.3	0.2	12.5	68
Total	137.9		114.5			1331

[1] The biomass estimate for molluscs was reduced by 90% reflecting two sources of reduction: (i) the reduction from whole to organic weight and (ii) the large density estimates (as high as 3,400 $t\cdot km^2$) are derived from studies which specifically Banquereau

Bank where bivalve mollusc density is high and not typical of the whole eastern Scotian Shelf.

BIOMASS ACCUMULATION

There is insufficient data to estimate biomass accumulation.

PRODUCTION:BIOMASS

In the absence of specific P/B estimates for the eastern Scotian Shelf, estimates of P/B used in the Newfoundland-Labrador Ecopath model (Bundy et al. 2000) were used (Table 46). There were detailed as follows:

Echinoderms

Robertson (1979) estimated an annual P/B of 0.65 yr^{-1} and Jarre-Teichmann and Guenette (1996) used an estimate of 0.6 yr^{-1} for the southern BC shelf. In the absence of other information, the lower of the two estimates, 0.6 yr^{-1} is used here.

Bivalve Molluscs

Robertson (1979) estimated a P/B of 0.76 yr^{-1} for molluscs and Jarre-Teichmann and Guenette (1996), based on their interpretation of Brey's (1995) database on macrobenthic productivity, estimated a mean P/B of 0.7 yr^{-1} for molluscs on the southern shelf of British Columbia. A value of 0.7 yr^{-1} is used here.

Polychaetes

Estimates of polychaete P/B ratios range between 2 and 3 yr^{-1} (Mills and Fournier 1979, Collie 1987, Jarre-Teichmann and Guenette 1996). Curtis (1977) estimated a lower value of 1.4 yr^{-1} for polychaetes off West Greenland. To allow for the higher estimates originating in warmer waters (and therefore having a greater productivity), the lower bound of 2 yr^{-1} is used.

Other Benthic Invertebrates (OBI)

Little is know about production of the OBI. The amphipods are assumed to represent this group. P/B estimates for amphipods range from 2.5 to 4.4 yr^{-1} on Georges Bank (NE USA) (Collie 1985), and 2.5 yr^{-1} (Mills and Fournier 1979) and 2.5 yr^{-1} (Jarre-Teichmann and Guenette 1996). The common estimate of 2.5 yr^{-1} is used

The total benthic production is 127 $t \cdot km^{-2} \cdot yr^{-1}$. The greatest production is by the echinoderms and molluscs. This compares to a total mean macrobenthic production of between 12 and 533 $t \cdot km^{-2} \cdot yr^{-1}$ on Browns Bank, Nova Scotia (Wildish *et al.* 1989), and 360 $t \cdot km^{-2} \cdot yr^{-1}$ on Georges Bank (Sissenwine *et al.* 1984).

CONSUMPTION:BIOMASS

As with the P/B ratios, these data are taken from Bundy et al. (2000) due to lack of information for these groups on the eastern Scotian Shelf. The Q/B ratio is estimated from the gross efficiency (GE) for all four benthic groups. Jarre-Teichmann and Guenette (1996) estimated GE for benthic groups on the southern BC Shelf. Using their values, the molluscs, polychaetes and echinoderms, all detritus feeders (see below) have a GE of 9%, or 0.09. The other benthic invertebrates have a GE of 20%. These GE values equate to the Q/B and consumption rates shown in Table 44. The greatest consumption is by molluscs and echinoderms, followed by polychaetes, then other benthic invertebrates.

Diet

As with the P/B and Q/B ratios, these data are taken from Bundy et al. (2000) due to lack of information for these groups on the eastern Scotian Shelf. Much of the diet information on these benthic groups originates in the work of Nesis (1965) and Hutcheson et al.(1981). Here, the diets are described in terms of the groupings used in the Ecopath model. Essentially, they are all described as benthic feeders. It should be noted however, that these data are simplified. It was not possible to review all the available information on congeneric and conspecifics in the literature.

Echinoderms

The echinoderms are basically detritivores. The sand dollar, *Echinarchnius parma*, the most common echinoderm in the study area, is a surface detritivore (Hutcheson *et al.* 1981, Mooi and Telford 1982). The sea urchin, *Stronglyocentrotus pallidus*, eats animal remains and detritus (Gilkinson *et al.* 1988), and the brittle star, *Ophiura robusta,* is a detritivore (Nesis 1965). The diet of this group then is 100% detritus.

Bivalve Molluscs

Some species of bivalve mollusc are suspension feeders and others are detrital and phytoplakton feeders. Suspension feeders feed on organic detrital matter that is re-suspended in the water immediately above the sediment surface. Deposit feeders can be considered detrital feeders. A study of scallops indicates that scallops eat detritus and phytoplankton and that the proportions of each vary with depth. It is assumed here that 50% of the bivalve mollusc diet is phytoplankton and 50 % is detritus.

Polychaetes

The polychaetes are detritivores and have a diet of 100% detritus (Nesis 1965, Fauchuld and Jumars 1979).

Other Benthic Invertebrates (OBI)

Gammarid amphipods, the representative species for this group, feed on organic detritus (Nesis 1965, Hutcheson *et al.* 1981). The *Cumacea* and *Isopoda* are also detritivores (Hutcheson *et al.* 1981.

ZOOPLANKTON

BACKGROUND

Zooplankton are an important link in marine food webs. They transfer organic carbon from phytoplankton to fish or marine mammals higher in the food chain, they are a food source for a broad spectrum of species and they contribute fecal matter and dead zooplankton to the benthic communities.

The zooplankton are treated here as two groups. The large zooplankton group are greater than 10 mm in length and include euphausiids, chaetognaths, hyperiid amphipods, Cnidarians and Ctenophores (jellyfish), mysids, tunicates >5 mm and icthyoplankton. This group feeds herbivorously (some euphausiid species), omnivorously (most euphuasiids, hyperiid amphipods, mysiids and large tunicates) and carnivorously (chaetognaths and jellyfish, Cnidarians and Ctenophores). The small zooplankton, includes zooplankton less than or equal to 10 mm in length. Copepods, mainly *Calanus finmarchicus*, and *Oithona similis* are the most numerous small plankton. Other small plankton include tunicates < 5 mm and meroplankton. *C. finmarchicus*, and *O. similis* are omnivorous.

36. LARGE ZOOPLANKTON

CATCH

None.

BIOMASS

There have been no systematic surveys of large zooplankton on the Scotian Shelf, with the exception of the Continuous Plankton Recorder which began in 1961 but was discontinued in 1976,beginning again in 1991 until present. Unfortunately, there are no data for the 1980-1985 period. Compared to the long term mean, the abundance of euphausiids is less in the 1990s than prior to 1970s. However, this offers no information on the abundance of euphausiids in the 1980s.

Sameoto and Cochrane (1996) estimated an average biomass of krill of 10 $t{\cdot}km^2$ in the Emerald and Le Have Basins, and 2 $t{\cdot}km^2$ in other areas, based on net and accoustic data. Weighted over the whole area of the Scotian Shelf, this results in an average of 3 $t{\cdot}km^2$. Allowing for the biomass of other species present in the large zooplankton, this estimate was increased to 9 $t{\cdot}km^2$. This estimate was used for both time periods.

An attempt was made to obtain an estimate of total large zooplankton biomass using the DFO BioChem database. BioChem is a DFO Regional Application Oracle database that serves as a repository for biological and chemical marine environmental sample measurements. Scientific Research Missions originating from the various DFO Research Institutions are the primary source of information in the holdings. However, it was not possible to resolve inconsistencies in the data.

BIOMASS ACCUMULATION

There is insufficient data to estimate biomass accumulation.

PRODUCTION:BIOMASS

Mauchline (1985) estimated P/B ratios of euphausiid species in the Rockall Trough, in the Atlantic, west of Ireland. One of these species occur on the eastern Scotian Shelf *Meganyctiphanes norvegica* and one is the same genera, *Thysanoessa longicaudata*. The P/B ratios are 1.6 and 6.4 yr^{-1} respectively. Since *Meganyctiphanes norvegica* is the dominant euphausiid species on the eastern Scotian Shelf, and we do not know P/B rations for the other types of large zooplankton, a weighted average of these two P/B estimates is used. Assuming that *Meganyctiphanes norvegica* represents large zooplankton species with low P/B ratios that comprise 70% of the large zooplankton biomass and *Thysanoessa longicaudata*, represents other species with higher production, that comprise 30 % of the large zooplankton biomass, the weighted average is 3.04 yr^{-1}. This value is used for both time periods.

CONSUMPTION:BIOMASS

There is some information on Q/B values for the large zooplankton. Sameoto (1976) examined the energy budgets of 3 euphausiid species in the Gulf of St. Lawrence, which also occur on the eastern Scotian Shelf. Using his figures, a Q/B of 5 yr^{-1} was estimated for *Meganyctiphanes norvegica*, 16 yr^{-1} for *Thysanoessa inermis* and 37 yr^{-1} for *Thysanoessa raschii.* Heyraud (1979) collected *M. norvegica* from the waters of Nice, France and kept them under laboratory conditions at 13C and fed them *Artemia salina*. This produced a Q/B estimate of 40.15 yr^{-1}. This should be regarded as an upper limit due to the high temperature that these euphausiids were reared in. Jarre-Teichmann (1996) used a GE of 0.16 for krill in the Alaska Gyre. Purcell (1996) estimated a Q/B of 30 yr^{-1} for salps, and used a GE of 0.3 for jelly fish in the Alaska Gyre.

An average Q/B of 19.5 yr^{-1} was estimated for the 3 euphausiid species (Sameoto 1976), and is used to represent the Q/B of the large zooplankton for both time periods. The value may seem a little high, but it allows for the average Q/B of the group to reflect the tunicates which are voracious consumers (Knoechel and Steel-Flynn 1989).

DIET

Euphausiids eat detritus, phytoplankton, chaetognaths, amphipods and crustaceans (copepods) (Mauchline 1980). Chaetognaths eat copepods (Sullivan 1980) and jelly fish eat copepods (Smayda 1993). Since the relative proportions of these species in the large zooplankton group are unknown, a representative diet for the group might be said to be 38 % small zooplankton, 37% phytoplankton, 20% detritus and 5% cannibalism.

37. SMALL ZOOPLANKTON

BIOMASS

Until recently there have been no systematic surveys of small zooplankton on the Scotian Shelf, with the exception of the Continuous Plankton Recorder noted above. As with the large zooplankton there are no data for the 1980-1985 period. Compared to the long term mean, the abundance of *C. finmarchicus* is less in the 1990s than prior to 1970s. However, this offers no information on their abundance of in the 1980s.

Biomass estimated for copepods from the eastern Scotian Shelf were provided by Dr Erica Head and Mr Les Harris for 1995-2001 – see Appendix 4 for details. In the absence of specific biomass estimates for the 1980s, and no clear indication of trend, the 1995-2000 value of 34 $t{\cdot}km^{2}$ was used as a minimum estimate for the 1980s.

Table 47. Biomass of copepods on the Scotian Shelf (g WW $m^2 \equiv t{\cdot}km^2$.)

Year	Month	Density	Annual Average
1995	April	28.0	
	July	27.6	27.8
1996	May	11.4	
	June	8.9	10.1
1997	April	37.6	
	May	65.0	51.3
1998	April	22.3	
	Oct	14.2	18.3
1999	April	41.3	
	June	32.4	36.8
2000	April	33.6	33.6
2001	May	86.2	86.2
Average		34	30

BIOMASS ACCUMULATION

There is insufficient data to estimate biomass accumulation.

PRODUCTION:BIOMASS

McClaren *et al.* (1989) estimated annual P/B ratios for a range of copepod species on the Scotian Shelf. It is assumed that *C. finmarchius* is the representative species for this group. It has a P/B ratio of 8.4 yr^{-1}. It should be noted however, that the cyclopoid copepod, *Oithona similis* which also belongs to the small zooplankton, has a much higher P/B ratio of 23 yr^{-1} on the Scotian Shelf and the P/B ratios for tunicates ≤ 5 mm are not known. Thus there is some uncertainty concerning the average P/B value for small zooplankton.

CONSUMPTION:BIOMASS

There is minimal information on the Q/B values for copepods or the other members of this group. Christensen (1995a) assumed a gross efficiency of 0.3. Purcell (1996) estimated a Q/B of 90.4 yr^{-1} for small copepods in the Alaska Gyre, based on copepod ingestion and clearance rates. This value seems rather high. Assuming a GE of 0.3 would result in a Q/B of 28 yr^{-1}.

DIET

The two size classes of zooplankton feed on both autotrophic microplankton and heterotrophic microplankton, in addition to other diet components. However, in this model, both types of microplankton are grouped simply as phytoplankton. It is recognised that this ignores the dynamics of the microbial loop (Pomeroy 1979), and thus the potential contribution from the microbial loop to higher trophic levels. Thus the diet of the small zooplankton would mistakenly interpreted as herbivorous when taken at face value for it is assumed to be 100 % phytoplankton.

38. PHYTOPLANKTON

BACKGROUND

CPR data noted above also recorded abundance of phytoplankton diatoms and dinoflagellates and the biomass of these two groups is higher in the 1990s than it was prior to 1976. However, this data series does not tell us how abundance of phytoplankton compares in the early 1980s to the late 1990s. In order to estimate abundance (biomass) and primary productivity of phytoplankton in the 1980s and the 1990s, CZCS satellite data from 1980- 1985 and from SeaWiFS satellite data from 1998 to 2000 were used. Ship based measurements of chlorophyll 'a' and primary production were used for comparative purposes. These data were provided by Carla Caverhill, Ocean Science, BIO.

BIOMASS

Biomass is estimated from satellite estimates of surface chlorophyll using algorithms developed at BIO. The surface chlorophyll is integrated over depth using a stored chlorophyll depth profile that is based on monthly empirical ship-based studies for the region (for further explanation of the method, see Platt *et al.* 1991, Longhurst *et al.* 1995 and Sathyendranath *et al.* 1995). The wet weight biomass of phytoplankton is estimated from monthly empirical carbon:chlorophyll ratios from the Grand Banks (Hollibaugh and Booth 1981). This is then converted to grams wet weight by multiplying by a factor of 10. The average biomass of phytoplankton in 1980-1985 was 34.4 $t \cdot km^2$ and in 1998-2000 was 43.6 $t \cdot km^2$ (Tables 48 and 49). Ship based estimate of biomass compares well with the satellite data in the 1980s, but is only 50% of the 1998-2000 satellite estimate.

Table 48. Estimates of primary production, phytoplankton biomass and P:B ratio from CZCS satellite data for 1980-1985. Ship based estimates are given for comparison. Figures in brackets are standard deviations.

	PP	B	P/B
	$g.m^{-2}\ yr^{-1}$	gm^{-2}	yr^{-1}
1980	2420	21.6	111.9
1981	2695	48.2	56.0
1982	2871	41.5	69.2
1983	2569	27.8	92.4
1984	2481	26.7	93.0
1985	2511	40.6	61.9
Average	2591 (1308)	34.4 (10.8)	80.7
Ship Based data	2477	41.9	59.3

Table 49. Estimates of primary production, phytoplankton biomass and P:B ratio from SeaWiFs satellite data for 1998-2000. Ship based estimates are given for comparison. Figures in brackets are standard deviations.

		PP	B	P/B
		$g.m^{-2}\ yr^{-1}$	gm^{-2}	yr^{-1}
	1998	2250	41.8	53.9
	1999	2291	47.1	48.6
	2000	2261	41.8	54.1
Average		2268	43.6	52.2
		(1280)	(20.0)	
Ship Based data		1661	23.0	72.0

BIOMASS ACCUMULATION

There is insufficient data to estimate biomass accumulation.

PRODUCTION:BIOMASS

Satellite estimates of primary production are derived from estimates of surface chlorophyll "a" biomass and chlorophyll depth profiles (see above). A model is used to calculate surface light, then another model to compute how much light there is at each depth increment in the water column. Productivity by the chlorophyll at each depth and light level is estimated using stored ship-based photosynthesis parameters that are compiled by domain and season. Productivity at depth is then integrated over depth to the euphotic depth to give total productivity (see Platt *et al.* 1991; Longhurst *et al.* 1995; Sathyendranath *et al.* 1995).

The total primary production in the 1980-1985 and 1998-2000 were 2591 and 2268 $g.m^{-2}\ yr^{-1}$ and are not significantly different. The P:B ratio was estimated from the primary production estimates from the satellite data divided by the biomass estimates from satellite data. Due to differences in the biomass estimates, the P:B ratios appear different in the two time periods, but again, this difference is not significant.

39. DETRITUS

The detritus biomass was estimated using an empirical relationship derived by Pauly *et al.* (1993). It relates detritus biomass to primary productivity and euphotic depth.

$$\log_{10} D = -2.41 + 0.954 \log_{10} PP + 0.863 \log_{10} E \tag{4}$$

where,
D = detritus standing stock ($gC \cdot m^{-2}$ (grams of carbon per square metre)), PP = primary productivity ($gCm^{-2}\ year^{-1}$), E = euphotic depth (m).

The fit of the regression equation to the data is not very good, but as suggested by Pauly *et al.* (1993:13), it "might be considered sufficient in cases where no other information is available".

Primary production was described above. The euphotic depth is provided in the satellite data. These were substituted into equation (4) giving detritus biomass estimates of 21.4 $gC \cdot m^{-2}$ for 1980-1985 and 16.0 $gC \cdot m^{-2}$ for 1998-2000, or 214 $t \cdot km^{-2}$ and 160 $t \cdot km^{-2}$, using a conversion factor of 10 g wet weight = 1 gC (Christensen and Pauly 1992:20). Given the approximate nature of the estimation method, the range should be regarded as a gross approximation and an average of 187 $t \cdot km^{-2}$ is used as the detritus biomass estimate for both time periods.

Table 50. Input parameters for the 1980-1985 model

	Biomass $t \cdot km^{-2}$	P/B yr^{-1}	Q/B yr^{-1}	EE	P/Q	Catch $t \cdot km^{-2}$	BA $t \cdot km^{-2}$
1 Ceteaceans	0.229	0.04	10.17				
2 Grey Seals	0.025	0.124	11.8			0.000	0.002
3 Seabirds	0.012	0.25	132.5				
4 Large Cod	1.218	0.631	1.95			0.508	
5 Small Cod	0.756	1.1	5.02			0.015	
6 Large Silver hake	1.87	1.153	7.4197			0.411	
7 Small Silver Hake	3.21	1.017	7.773			0.115	
8 Haddock	0.84	0.45	5.19			0.124	
9 American plaice	1.077	0.25	1.2			0.055	-0.022
10 Large Halibut	0.054	0.23			0.15	0.008	
11 Small Halibut	0.016	0.46	2.75			0.000	
12 Flounders	0.652	0.341	2.7			0.026	-0.009
13 Skates	0.274	0.200	1.88			0.003	-0.015
14 Dogfish	0.241	0.23	2.6			0.003	
15 Redfish	5.758	0.242	6.13			0.063	
16 Pollock	0.976	0.311	3.59			0.125	
17 Transient Mackerel	0.592	0.29	2.2			0.012	
18 Large Demersal Piscivores	0.199	0.301	4.22			0.014	
19 Small Demersal Piscivores	0.086		5.2		0.15		
20 Large Demersal Feeders	0.087	0.344			0.15	0.007	
21 Small Large Demersal Feeders	0.154	0.7			0.15		
22 Small Demersal Feeders	0.032	0.5	4.27				
23 Capelin	0.028	0.7			0.15		
24 Sand lance	0.105	1.15			0.15		
25 Transient Pelagics	0.018	0.24	4			0.002	
26 Small Pelagics	1.15	0.51	4.59			0.004	
27 Small mesopelagics		1.4	5	0.95			
28 Squid	0.076		4.45		0.15	0.024	
29 Large Crabs	0.15	0.16	1.2			0.000	
30 Small Crabs		0.3	1.5	0.95			
31 Shrimp	0.102	1.7			0.15	0.003	
32 Echinoderms	63.7	0.6			0.09		
33 Polychaetes	11.9	2			0.09		
34 Bivalve Molluscs	57.4	0.7			0.09	0.005	
35 Other Benthic Invertebrates	4.9	2.5			0.2		
36 Large Zooplankton	9	3.0	19.5				
37 Small zooplankton	34	8.4			0.3		
38 Phytoplankton	34.4	80.7					
39 Detritus	187						

Table 51. Diet Input for 1980-1985 model.

Input	1	2	3	4	5	6	7	8	9	10	11	12	13
Prey \ Predator	Cetea	Seals	Birds	L.Cod	S.Cod	L.Shak	S.Shak	Hadd	A. plaice	L.Hal	S.Hal	Flats	Skates
1 Cetea													
2 Seals													
3 Birds			0.001										
4 L.Cod		0.018				0.001							0.000
5 S.Cod	0.013	0.166	0.005	0.014	0.004			0.009		0.031			0.050
6 L.Shak		0.027				0.013							0.000
7 S.Shak	0.008	0.140		0.080	0.002	0.146	0.029	0.009	0.006	0.063	0.003		0.004
8 Hadd		0.092	0.005	0.010		0.001		0.009		0.094	0.005		0.000
9 A.plaice		0.035		0.002				0.001	0.001	0.131	0.016		0.000
10 L.Hal													0.000
11 S.Hal				0.001									0.000
12 Flats		0.020		0.004				0.001	0.000	0.031	0.007		0.001
13 Skates		0.037								0.028			0.000
14 Dogfish													0.000
15 Redfish	0.005			0.009	0.001	0.001		0.004	0.000		0.003		0.011
16 Pollock				0.014	0.002								0.000
17 T.Mack.	0.039	0.016											0.000
18 LDPisc	0.002			0.003									0.000
19 SDPisc	0.002			0.010						0.063			0.000
20 LDF	0.002			0.008									0.000
21 SLDF	0.002			0.070	0.001			0.000	0.000	0.031	0.018		0.042
22 SDFs			0.016	0.007	0.003			0.005	0.000		0.020		0.075
23 Cap									0.001		0.002		0.000
24 Slance	0.150	0.111	0.129	0.087	0.100	0.017	0.004	0.060	0.001	0.250	0.273		0.069
25 T.Pels													0.000
26 S.Pels	0.040	0.058	0.092	0.020	0.003	0.037	0.007	0.001	0.000	0.088	0.002		0.002
27 Mesop			0.008			0.141	0.073	0.000					0.000
28 Squid	0.125	0.033	0.067	0.009	0.001	0.180	0.031	0.002	0.000	0.031	0.019		0.037
29 LCrab				0.001				0.000					0.000
30 SCrab		0.033	0.015	0.153	0.051			0.007	0.028	0.063	0.143		0.118
31 Shrimp		0.033	0.015	0.085	0.117	0.009	0.040	0.029	0.029	0.094	0.309	0.080	0.058
32 Echin			0.015	0.027	0.021			0.422	0.795	0.003	0.007	0.050	0.000
33 Polyc		0.033	0.015	0.032	0.059			0.098	0.028		0.018	0.630	0.404
34 Moll		0.033	0.015	0.022	0.049			0.046	0.046		0.007	0.010	0.056
35 OBI		0.115	0.015	0.052	0.041	0.052	0.007	0.075	0.017			0.050	0.021
36 LZP	0.604		0.432	0.266	0.525	0.402	0.808	0.183	0.047		0.148	0.170	0.035
37 SZP	0.007			0.012	0.020	0.001	0.001	0.037					0.015
38 PHYP													0.000
39 DET													0.000
40 Import			0.156										
41 Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 51 (cont). Diet Input for 1980-1985 model.

Input	14	15	16	17	18	19	20	21	22	23	24	25	26
Prey \ Predator	Dogfish	Redfish	Pollock	T.Mack	LDPisc	SDPisc	LDF	SLDF	SDFs	Cap	Slance	T.Pels	S.Pels
1 Cetea													
2 Seals													
3 Birds												0.011	
4 L.Cod	0.005				0.009							0.000	
5 S.Cod	0.021				0.057	0.096	0.005	0.024				0.000	
6 L.Shak	0.011				0.011							0.071	
7 S.Shak	0.043		0.116		0.483	0.192	0.047		0.002			0.012	
8 Hadd					0.042	0.027	0.027					0.000	
9 A.plaice	0.003				0.019	0.023	0.005	0.020				0.000	
10 L.Hal												0.000	
11 S.Hal					0.001							0.000	
12 Flats	0.043				0.016	0.087	0.000					0.042	
13 Skates	0.000				0.019		0.002					0.007	
14 Dogfish					0.003							0.030	
15 Redfish			0.016		0.097	0.038	0.071	0.001				0.061	
16 Pollock					0.025	0.001		0.002				0.000	
17 T.Mack.	0.063				0.004							0.152	
18 LDPisc	0.002				0.004							0.015	
19 SDPisc	0.009				0.024							0.000	
20 LDF	0.011				0.001	0.005						0.060	
21 SLDF	0.043				0.038	0.051	0.018		0.001			0.000	
22 SDFs	0.026				0.017	0.009	0.001	0.005	0.012			0.000	
23 Cap										0.010		0.010	
24 Slance	0.218		0.054		0.001	0.004	0.043		0.013	0.010		0.001	
25 T.Pels												0.013	
26 S.Pels	0.031		0.092	0.083	0.048	0.005	0.007		0.005			0.082	
27 Mesop	0.001		0.020									0.030	
28 Squid	0.093		0.008		0.012	0.047	0.022					0.388	
29 LCrab						0.008	0.002					0.005	
30 SCrab	0.019				0.000	0.012	0.042	0.019	0.027			0.000	
31 Shrimp	0.017	0.279	0.032	0.028	0.062	0.296	0.083	0.156	0.050			0.000	0.046
32 Echin	0.000						0.265	0.045	0.090			0.000	
33 Polyc	0.008	0.001	0.011			0.011	0.007	0.355	0.188			0.000	
34 Moll	0.032				0.000	0.001	0.168	0.059	0.008			0.000	
35 OBI	0.007	0.008			0.007	0.046	0.055	0.035	0.477		0.039	0.005	0.100
36 LZP	0.280	0.673	0.631	0.585		0.042	0.115	0.280	0.076	0.434	0.209	0.005	0.513
37 SZP	0.013	0.040	0.021	0.304			0.011		0.051	0.546	0.712	0.000	0.341
38 PHYP												0.000	
39 DET							0.005				0.040	0.000	
40 Import													
41 Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.000

Table 51 (cont). Diet Input for 1980-1985 model.

	Input	27	28	29	30	31	32	33	34	35	36	37
	Prey \ Predator	Mesop	Squid	LCrab	SCrab	Shrimp	Echin	Polyc	Moll	OBI	LZP	SZP
1	Cetea											
2	Seals											
3	Birds											
4	L.Cod											
5	S.Cod		0.014									
6	L.Shak											
7	S.Shak		0.096									
8	Hadd		0.014									
9	A.plaice											
10	L.Hal											
11	S.Hal											
12	Flats											
13	Skates											
14	Dogfish											
15	Redfish											
16	Pollock		0.014									
17	T.Mack.											
18	LDPisc											
19	SDPisc		0.014									
20	LDF											
21	SLDF		0.060									
22	SDFs											
23	Cap	0.001										
24	Slance											
25	T.Pels											
26	S.Pels											
27	Mesop	0.050	0.140									
28	Squid	0.040	0.252									
29	LCrab											
30	SCrab		0.023	0.025								
31	Shrimp			0.085								
32	Echin			0.243	0.153							
33	Polyc			0.108	0.144	0.015						
34	Moll			0.007	0.012							
35	OBI			0.284	0.435	0.015						
36	LZP	0.459	0.309	0.148	0.157	0.120					0.050	
37	SZP	0.450	0.067			0.240					0.380	
38	PHYP					0.085			0.500		0.370	1.000
39	DET			0.100	0.100	0.525	1.000	1.000	0.500	1.000	0.200	
40	Import											
41	Sum	1.000		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 52. Input parameters for the 1995-2000 model

	Biomass $t \cdot km^{-2}$	P/B yr^{-1}	Q/B yr^{-1}	EE	P/Q	Catch $t \cdot km^{-2}$	BA $t \cdot km^{-2}$
1 Ceteaceans	0.260	0.04	10.17				
2 Grey Seals	0.142	0.124	11.8				0.017
3 Seabirds	0.012	0.25	132.5				
4 Large Cod	0.073	1.04	1.95			0.003	
5 Small Cod	0.095	2.2	5				
6 Large Silver hake	0.49	0.93437	5.51			0.060	
7 Small Silver Hake	3.71	1.06946	5.8			0.153	
8 Haddock	0.495	0.51	5.19			0.001	
9 American plaice	0.604	0.21	1.2			0.005	
10 Large Halibut	0.011	0.5			0.15	0.003	
11 Small Halibut	0.101	0.46	2.75			0.000	0.006
12 Flounders	0.668	0.31	2.7			0.006	
13 Skates	0.098	0.20	1.88			0.010	
14 Dogfish	0.105	0.21	2.6			0.000	
15 Redfish	2.556	0.222	6.13			0.025	
16 Pollock	0.442	0.306	3.59			0.013	
17 Transient Mackerel	0.214	0.29	2.2			0.005	
18 Large Demersal Piscivores	0.048	0.363	4.22			0.007	
19 Small Demersal Piscivores	0.078		5.2		0.15		
20 Large Demersal Feeders	0.043	0.274			0.15	0.002	
21 Small Large Demersal Feeders	0.087	0.6			0.15		
22 Small Demersal Feeders	0.119	0.5	4.27				
23 Capelin	2.9		6.68		0.15		
24 Sand lance	22.38	0.62	4.07				
25 Transient Pelagics	0.009	0.24	4.0			0.010	
26 Small Pelagics	17.1	0.468	4.6			0.026	
27 Small mesopelagics		1.4	5	0.95			
28 Squid	0.04		4.45		0.15	0.008	
29 Large Crabs	0.308	0.16	1.2			0.035	
30 Small Crabs	3.78	0.3	1.5			0.001	
31 Shrimp	0.201	1.7			0.15	0.034	
32 Echinoderms	63.7	0.6			0.09	0.002	
33 Polychaetes	11.9	2			0.09		
34 Bivalve Molluscs	57.4	0.7			0.09	0.080	
35 Other Benthic Invertebrates	4.9	2.5			0.2		
36 Large Zooplankton	9	3.04	19.5				
37 Small zooplankton	34	8.4			0.3		
38 Phytoplankton	43.6	52.2					
39 Detritus	187						

Table 53. Diet Input for 1995-2000 model.

Input	1	2	3	4	5	6	7	8	9	10	11	12	13
Prey \ Predator	Cetea	Seals	Birds	L.Cod	S.Cod	L.Shak	S.Shak	Hadd	A.plaice	L.Hal	S.Hal	Flats	Skates
1 Cetea													
2 Seals													
3 Birds			0.001										
4 L.Cod		0.001											
5 S.Cod	0.011	0.015	0.005	0.084	0.002	0.011		0.000		0.031			
6 L.Shak		0.005											
7 S.Shak	0.007	0.028		0.008		0.058	0.012	0.001	0.006	0.063	0.003		0.003
8 Hadd		0.005	0.005	0.004		0.059		0.001		0.094	0.001		
9 A.plaice		0.032		0.113				0.000	0.001	0.131	0.008		
10 L.Hal													
11 S.Hal		0.001											
12 Flats		0.054		0.009				0.000	0.001	0.031	0.025		
13 Skates		0.028								0.028			
14 Dogfish													
15 Redfish	0.004	0.052		0.004	0.005			0.027	0.000		0.026	0.007	0.002
16 Pollock		0.004		0.021	0.009	0.007	0.012						
17 T.Mack.	0.034												
18 LDPisc	0.002	0.000											
19 SDPisc	0.002	0.002								0.063			
20 LDF	0.002	0.001											
21 SLDF	0.002	0.009		0.003	0.001			0.000	0.001	0.031	0.012		0.002
22 SDFs		0.103	0.008	0.005	0.006	0.001	0.002	0.001	0.001		0.021		
23 Cap		0.200	0.001	0.004	0.014	0.366	0.017		0.068		0.242	0.002	0.004
24 Slance	0.188	0.408	0.276	0.230	0.154	0.148	0.084	0.053	0.108	0.250	0.286	0.052	0.100
25 T.Pels													
26 S.Pels	0.035	0.009	0.092	0.146	0.045	0.073	0.003	0.009	0.000	0.088	0.015		0.004
27 Mesop			0.008										
28 Squid	0.120	0.044	0.010	0.005			0.002	0.002	0.001	0.031	0.005		0.001
29 LCrab					0.005			0.000					0.002
30 SCrab			0.015	0.019	0.028			0.008	0.013	0.063	0.003		0.053
31 Shrimp		0.001	0.015	0.288	0.300	0.049	0.594	0.029	0.187	0.094	0.195	0.028	0.086
32 Echin			0.015					0.024	0.042	0.003	0.007	0.001	
33 Polyc			0.015	0.013	0.034			0.442	0.208		0.001	0.417	0.141
34 Moll			0.015	0.002	0.000			0.009	0.013		0.007	0.007	
35 OBI			0.015	0.013	0.062		0.003	0.109	0.117			0.091	0.108
36 LZP	0.586		0.432	0.029	0.333	0.228	0.269	0.249	0.232		0.145	0.393	0.493
37 SZP	0.006				0.001			0.037					
38 PHYP													
39 DET			0.015										
40 Import	0		0.056										
41 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 53. Diet Input for 1995-2000 model (cont.).

Input	14	15	16	17	18	19	20	21	22	23	24	25	26
Prey \ Predator	Dogfish	Redfish	Pollock	T.Mack.	LDPisc	SDPisc	LDF	SLDF	SDFs	Cap	Slance	T.Pels	S.Pels
1 Cetea													
2 Seals													
3 Birds												0.011	
4 L.Cod	0.001												
5 S.Cod	0.005		0.001		0.021	0.054	0.024	0.024	0.001				
6 L.Shak	0.001											0.067	
7 S.Shak	0.197		0.029		0.131	0.060			0.015			0.012	
8 Hadd	0.016		0.062		0.181	0.030							
9 A.plaice	0.140					0.026	0.020	0.020					
10 L.Hal													
11 S.Hal													
12 Flats	0.006		0.000		0.092	0.097			0.007			0.040	
13 Skates												0.007	
14 Dogfish												0.028	
15 Redfish	0.013	0.002	0.084		0.016	0.042	0.001	0.001	0.005		0.002	0.058	
16 Pollock			0.001		0.001	0.001	0.002	0.002	0.001				
17 T.Mack.	0.001											0.144	
18 LDPisc	0.000											0.014	
19 SDPisc	0.001												
20 LDF	0.000				0.073	0.005						0.057	
21 SLDF	0.000				0.038	0.057			0.018				
22 SDFs	0.000	0.006			0.013	0.010	0.019	0.019	0.004				
23 Cap									0.003	0.035		0.040	
24 Slance	0.038	0.001	0.051		0.047	0.045	0.050		0.370			0.001	
25 T.Pels												0.013	
26 S.Pels	0.261		0.154	0.083	0.172	0.058			0.001			0.078	
27 Mesop	0.001	0.031	0.002									0.028	
28 Squid	0.040	0.004	0.024		0.079	0.053			0.002			0.388	
29 LCrab					0.001	0.009	0.010		0.000			0.005	
30 SCrab	0.002		0.005		0.003	0.014	0.126	0.032	0.041				
31 Shrimp	0.091	0.569	0.149	0.028	0.124	0.331	0.276	0.259	0.091	0.362	0.134		0.046
32 Echin							0.087	0.037	0.009		0.005		
33 Polyc	0.001		0.000			0.012	0.135	0.295	0.043	0.293			
34 Moll	0.003					0.001	0.013	0.049	0.001				
35 OBI	0.177	0.117	0.010		0.009	0.051	0.142	0.029	0.026			0.005	0.100
36 LZP	0.002	0.266	0.427	0.585	0.001	0.046	0.094	0.233	0.359	0.309	0.723	0.005	0.411
37 SZP	0.001	0.004		0.304					0.000		0.097		0.443
38 PHYP									0.004				
39 DET											0.04		
40 Import													
41 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 53. Diet Input for 1995-2000 model (cont.).

Input	27	28	29	30	31	32	33	34	35	36	37
Prey \ Predator	Mesop	Squid	LCrab	SCrab	Shrimp	Echin	Polyc	Moll	OBI	LZP	SZP
1 Cetea											
2 Seals											
3 Birds											
4 L.Cod											
5 S.Cod		0.014									
6 L.Shak											
7 S.Shak		0.096									
8 Hadd		0.014									
9 A.plaice											
10 L.Hal											
11 S.Hal											
12 Flats											
13 Skates											
14 Dogfish											
15 Redfish											
16 Pollock		0.014									
17 T.Mack.											
18 LDPisc											
19 SDPisc		0.014									
20 LDF											
21 SLDF		0.060									
22 SDFs											
23 Cap	0.010										
24 Slance											
25 T.Pels											
26 S.Pels											
27 Mesop	0.050	0.140									
28 Squid	0.040	0.252									
29 LCrab											
30 SCrab		0.023	0.025								
31 Shrimp		0.000	0.085								
32 Echin			0.243	0.153							
33 Polyc			0.108	0.144	0.015						
34 Moll			0.007	0.012							
35 OBI			0.284	0.435	0.015						
36 LZP	0.450	0.309	0.148	0.157	0.120					0.050	
37 SZP	0.450	0.067			0.240					0.380	
38 PHYP	-				0.085			0.5		0.37	1
39 DET			0.1	0.100	0.525	1	1	0.5	1	0.2	
40 Import		0.343									
41 Sum	1	1	1	1	1	1	1	1	1	1	

RESULTS

Neither of the two models was balanced when the missing parameters were estimated. This is the usual case, and the models were made to balance using an iterative procedure, altering input parameters within the bounds of uncertainty. Three central criteria were used when balancing the models:

1. Key anchor groups were identified at each trophic level. The information for these groups is considered more certain than that of other groups and their parameters were altered as little as possible. Anchor groups were:

Functional Group	Trophic level
Grey seals (TL=4)	4
Large silver hake (TL=4)	4
Large cod (TL=4)	4
Haddock (TL=3)	3
Small zooplankton (TL=2).	2

In general there is more certainty at higher trophic levels than at lower trophic levels, a situation common to many ecosystem modelling efforts.

2. There are essentially five input parameters that can be adjusted when balancing an Ecopath model; biomass, P/B, Q/B, EE and diet. All have different degrees of uncertainty, depending on the functional groups that they represent. Generally though, the diet has the most uncertainty associated with it, so this is often altered in this first instance.
3. In the balancing of the two models for 1980-1985 and 1995-2000, consistency between models is taken into consideration. In particular, for the fish species the RV survey provides a good estimate of the relative difference in fish biomass between the two time periods, and this was used as a check to ensure model relevancy.

The initial results and main changes to the model input parameters are summarised below for each time period.

1980-1985

The results in Table 54 show that eleven groups had an ecotrophic efficiency greater than 1. This means that more production is being consumed than is actually being produced, which is not possible. It is useful to look at these groups first when balancing a model, to find out where the main imbalances are and to try to correct them.

Table 54. Initial Parameter estimates, 1980-1985 (Model estimates are in italics).

Group name	Trophic level	Biomass	P/B yr^{-1}	Q/B yr^{-1}	EE	P/Q	Respiration /biomass
1 Ceteaceans	*3.87*	0.229	0.04	10.17	*0*	*0.004*	*8.096*
2 Grey Seals	*4.12*	0.025	0.124	11.8	*0.71*	*0.011*	*9.316*
3 Seabirds	*3.78*	0.012	0.25	132.5	*0.785*	*0.002*	*105.75*
4 Large Cod	*3.79*	1.218	0.631	1.95	*0.697*	*0.324*	*0.929*
5 Small Cod	*3.47*	0.756	1.1	5.02	*0.656*	*0.219*	*2.916*
6 Large Silver hake	*4.11*	1.87	1.153	7.42	*0.287*	*0.155*	*4.783*
7 Small Silver Hake	*3.61*	3.21	1.017	7.773	*1.269*	*0.131*	*5.201*
8 Haddock	*3.23*	0.84	0.45	5.19	*0.798*	*0.087*	*3.702*
9 American plaice	*3.08*	1.077	0.25	1.2	*0.358*	0.208	*0.71*
10 Large Halibut	*4.19*	0.054	0.23	*1.533*	*0.681*	0.15	*0.997*
11 Small Halibut	*3.76*	0.016	0.46	2.75	*0.486*	0.167	*1.74*
12 Flounders	*3.11*	0.652	0.341	2.7	*0.548*	0.126	*1.819*
13 Skates	*3.55*	0.274	0.2	1.88	*0.736*	0.106	*1.304*
14 Dogfish	*4.02*	0.241	0.23	2.6	*0.14*	*0.088*	*1.85*
15 Redfish	*3.43*	5.758	0.242	6.13	*0.223*	*0.039*	*4.662*
16 Pollock	*3.73*	0.976	0.311	3.59	*0.637*	*0.087*	*2.561*
17 Transient Mackerel	*3.38*	0.592	0.29	2.2	*0.892*	0.132	*1.47*
18 Large Demersal Piscivores	*4.46*	0.199	0.301	4.22	*0.53*	*0.071*	*3.075*
19 Small Demersal Piscivores	*4.03*	0.086	*0.78*	5.2	*0.958*	0.15	3.38
20 Large Demersal Feeders	*3.48*	0.087	*0.344*	2.293	*1.483*	0.15	*1.491*
21 Small Large Demersal Feeders	*3.28*	0.154	0.7	*4.667*	*2.839*	0.15	*3.033*
22 Small Demersal Feeders	*3.12*	0.032	0.5	4.27	*9.588*	*0.117*	*2.916*
23 Capelin	*3.22*	0.028	0.7	*4.667*	*1.077*	0.15	*3.033*
24 Sand lance	*3.05*	0.105	1.15	7.667	*18.036*	0.15	*4.983*
25 Transient Pelagics	*4.8*	0.018	0.24	4	*1.11*	*0.060*	*2.96*
26 Small Pelagics	*3.25*	1.15	0.51	4.59	*2.594*	*0.111*	*3.162*
27 Small mesopelagics	*3.37*	3.62	1.4	5	0.95	*0.28*	*2.6*
28 Squid	*4.24*	0.076	0.667	4.45	*92.975*	0.15	*2.893*
29 Large Crabs	*3.03*	0.15	0.16	1.2	*0.334*	*0.133*	*0.8*
30 Small Crabs	*2.97*	2.758	0.3	1.5	0.95	*0.2*	*0.9*
31 Shrimp	*2.44*	0.102	1.7	11.333	*73.425*	0.15	*7.367*
32 Echinoderms	*2*	63.7	0.6	6.667	*0.102*	*0.09*	*4.733*
33 Polychaetes	*2*	11.9	2	22.222	*0.131*	*0.09*	*15.778*
34 Bivalve Molluscs	*2*	57.4	0.7	7.778	*0.018*	*0.09*	*5.522*
35 Other Benthic Invertebrates	*2*	4.9	2.5	12.5	*0.369*	*0.2*	7.5
36 Large Zooplankton	*2.45*	9	3.04	19.5	*2.914*	0.156	*12.56*
37 Small zooplankton	*2*	34	8.4	*28*	*0.279*	0.3	*14*
38 Phytoplankton	*1*	34.384	80.731	-	*0.447*	-	-
39 Detritus	*1*	187	-	-	*0.888*	-	-

Groups with Ecotrophic efficiency greater than 1

Shrimp, sand lance, squid and small demersals:

In the case of shrimp, squid, small demersals and sand lance, the EE is very large, indicating a mis-specification somewhere in the model. None of these groups are anchor groups and their biomass is poorly estimated. The diet of their predators, including cetaceans, seabirds, small cod, silver hake and dogfish, was first adjusted to decrease the consumption of these species, then the biomass was estimated by the model by setting the ecotrophic efficiency set to default 0.95. Where squid appeared in the diet, a large proportion was treated as import to the diet, assuming that it was consumed off the shelf edge, by predators such as cetaceans, transient pelagics and cannibalism within the group. This was necessary in order to reduce the biomass of squid to a value that is meaningful, and to reduce consumption by squid on groups such as the small large demersal feeders.

Large demersal feeders, Small large demersal feeders (small LDFs)

In order to reduce the EE, the proportion of both large demersal feeders and small LDFs was reduced in the large cod diet, and the small LDFs were reduced in the small demersal piscivore and squid diets. The diet of the transient pelagics contains both large and small LDFs. The proportion was altered so that transient pelagics eat more small LDFs, which is more likely. The biomass was then estimated by the model, setting the EE to 0.95.

Small Pelagics

The ecotrophic efficiency of this group was reduced by reducing the proportion of small pelagics in the diets of the seabirds, silver hake, small silver hake and pollock. The model then estimated the biomass, assuming EE=0.95.

Capelin

Capelin EE is reduced below 1 as a result of the reduction in mesopelagic biomass (see below).

Transient Pelagics

The biomass of the transient pelagics was increased to 0.046 t·km^{-2}. This was the biomass required in the 1995-2000 model for this groups to balance, and since it is not known whether the biomass of transient pelagics has changed between the two time periods, they were made consistent. In addition, cannibalism was reduced in the diet from 1.3 % to 0.005%.

Small silver hake

Small silver hake was reduced in the diets of predators such as silver hake, pollock and squid. Cannibalism was also reduced. The EE was set to 0.95 and the model estimated the biomass. Note that the resultant biomass (Table results) is less than the q-adjusted biomass but this is OK, since the q-adjusted biomass may be treated as an upper limit.

Large zooplankton

Large zooplankton was reduced in the diet of small cod, and cannibalism was reduced. The EE was then set to 0.95 and the model allowed to estimate the biomass. Other changes to the model such as the reduction of the biomass of silver hake and redfish (see below) reduced the estimated biomass of large zooplankton.

Groups with large biomass estimates

Silver hake

Large silver hake biomass was estimated from q-adjusted RV trawl survey data. However, the estimated ecotrophic efficiency is very low, particularly for a commercial species. There is also a SPA estimate of large silver hake biomass, which is approximately 50% of the q-adjusted estimated. This was used in place of the q-adjusted estimate, giving an ecotrophic efficiency of 0.56. Note that by reducing the biomass of the large silver hake, the biomass of small silver hake, estimated by the model, is also reduced. The biomass of both large and small silver hake is thus reduced from the q-adjusted biomass estimate in the process of balancing the model. Since silver hake are a major predator of large zooplankton, this also reduces their predation impact on large zooplankton.

Redfish

The biomass of redfish, estimated from catchability adjusted RV biomass estimates is very large (5.8 t·km^{-2} or 589, 187 t), the EE is low, and redfish have large impact on large zooplankton and shrimp. The q-adjusted biomass estimate is likely to be too large. It is assumed that this biomass marks the extreme high end of the range of likely values, and the biomass was reduced to 3.4 t·km^{-2}, which is in the middle of the range.

Biomass is estimated for two groups in the initial model, small mesopelagics and small crabs. Both are large, relative to the biomass of other groups in the model and to the little that we know about these groups.

Small mesopelagics

In order to reduce the biomass of mesopelagics, they were reduced significantly in the diets of silver hake, small silver hake and squid. They were assumed to be imported from deeper waters since mesopelagics, squid and silver hake all occur in deeper water outside the model area.

Small Crabs

Small crabs were reduced in the diets of large and small cod and squid.

P/Q too high or too low

The production/consumption ratio should be between 0.1 and 0.3 for most species (Christensen and Pauly 1992).

The following functional groups had P/Q values less than 0.1 (Table 55):

- Haddock Q/B was estimated from empirical data for the eastern Scotian Shelf. There is a lower estimate of 3.0 yr^{-1} for haddock Q/B from Georges Bank (Pauly 1989). It is assumed here that Q/B is midway between these two estimates, ie, Q/B=4 yr^{-1}.
- Spiny dogfish Q/B was reduced from 2.6 yr^{-1} to 2 yr^{-1}, which is within the likely range of uncertainty of this parameter.
- Redfish Q/B was estimated as 6.13 yr^{-1} from consumption studies on the eastern Scotian Shelf. However, estimates from an earlier study by Dolgov and Drevetnyak (1990) were considerably lower than this. The value of 2 yr^{-1}, derived from these estimates by Bundy et al. (2000) was used.
- Pollock and demersal piscivores Q/B was estimated from consumption studies on the eastern Scotian Shelf. Both were reduced to 3.0 yr^{-1}, which is within the likely range of uncertainty.
- Transient pelagics Q/B was the average of values in the literature for areas other than the eastern Scotian Shelf. It produced a very low P/Q of 0.06, although it is within the range described above. However, Q/B was reduced by 50% to 2 yr^{-1}.

Table 55. Original and adjusted values of Q/B and P/Q (1980-1985 model).

	Original Q/B	Adjusted Q/B	Original P/Q	Balanced P/Q
Haddock	5.19	4.0	0.087	0.112
Spiny dogfish	2.60	2.0	0.088	0.115
Redfish	6.13	2.0	0.039	0.121
Pollock	3.59	3.0	0.087	0.117
Dem. Piscivores	4.22	3.0	0.071	0.100
Trans. Pels	4.00	2.0	0.060	0.120
Cod > 40 cm	1.95	2.1	0.324	0.300

Large cod had a P/Q value greater than 0.3 (Table 55). In order to reduce this, the Q/B was adjusted upwards to 2.1 yr^{-1}. This estimate is within the range of estimates of cod Q/B described above.

Other changes to input parameters

Seabirds

The respiration/biomass ratio is greater than 100 and is much higher than any of the R/B ratios for the other groups (Table 54). Whilst seabirds do use a lot of energy, and thus have a high respiration, this was considered unrealistic. In order to reduce the R/B, the Q/B was reduced from 132 yr^{-1} to 55 yr^{-1}. This is consistent with empirical values described for seabirds in the Gulf of St. Lawrence (Morissette et al. 2003). This reduced the R/B to 44 yr^{-1}.

Small cod

The P/B of small cod was reduced from 1.1 to 0.75 yr^{-1}. P/B was calculated from production estimates from an SPA. Transfers to older age groups were included as part of the production, and hence mortality. Christensen et al. (2000) indicate that the transfer to older age groups should not be included in the estimate. If these are excluded, the P/B=0.3 yr^{-1}, and this basically reflect the assumed input natural mortality. There is no real alternative method to estimate the P/B of small cod. Given this absense, P/B was assumed to be somewhere between 0.3 and 1.1 and a value of 0.75 yr^{-1} was used.

Pollock

Due to changes in made to the model in the course of balancing, the EE of pollock increased to a value greater than 1. In order to reduce this, the P/B was increased from 0.311 to 0.35, which is within the range of likely uncertainty for this parameter.

Small demersals

In order to reduce the biomass estimate (see also above), the P/B was increased from 0.4 to 0.65 yr^{-1}. This is within the range of likely values.

Diet Changes in addition to those already described

Large cod

The large cod diet was adjusted to reduce the consumption of large demersal feeders and small LDFs, and small crabs, and the difference distributed over the other fish groups, and invertebrate groups respectively.

Small cod

Sand lance, small demersals and small crabs and large zooplankton were reduced in the small cod diet. Small amount of capelin added to the diet.

Large Silver hake

Mesopelagics and squid were reduced in the large silver hake diet and the difference attributed to import (see above). Small pelagics were reduced to a third. Some of this was attributed to pollock since pollock are present in the 1995-2000 diet, and the rest put to import. Small silver hake was reduced by 50 %, and the difference distributed to pollock and other benthic invertebrates.

Spiny Dogfish

American plaice was increased since it was much higher in the 1995-2000 diet for the eastern Scotian Shelf. Other benthic invertebrates were also increased, to compensate for the decrease in sand lance.

Small demersal piscivores

Small cod were reduced by 20% and small LDFs were reduced by 50%, then the diet normalised.

Small large demersal feeders (Small LDFs)

Small cod were reduced by 50% and the diet then normalised.

Transient pelagics

Seabirds were reduced in this diet because they were far too sensitive to changes in the transient pelagic biomass when running simulation with Ecosim. Other changes included changing large demersal piscivores in the diet to small demersal piscivores. The diet of the transient pelagics contains both large and small LDFs. The proportion was altered so that transient pelagics eat more small LDFs, which is more likely. Squid in the diet was assumed to be imported from deeper waters outside the model boundary.

Squid

When the biomass of squid was estimated by the model, the biomass was sufficiently large to cause very high mortality on many of the fish species. Given the large uncertainty associated with squid diet, the small LDFs were reduced by 5/6 (83%) because the squid drive their biomass too high, and 90% of mesopelagics were assumed to be imported. Large zooplankton was increased slightly. All squid cannibalism was assumed to be imported. Finally, all groups in the diet were reduced by 50%, except small zooplankton, which was increased by 3. The remainder of the diet was treated as import from deeper waters.

Large zooplankton

Cannibalism was reduced, consumption of detritus was reduced and consumption of small zooplankton increased.

1995-2000

Groups with Ecotrophic efficiency greater than 1

The results in Table 56 show that fourteen groups had an ecotrophic efficiency greater than 1.

Shrimp

The ecotrophic efficiency of shrimp is very high, indicating a considerable imbalance between the production and consumption of this group. If the model is allowed to estimate biomass (set EE=0.95), it produces a biomass of 28.4 t·km^{-2}, or 2,900,000 tons which is too high. In the first instance, shrimp was reduced in the diets of its main predators, cod, small cod, silver hake, small silver hake, large demersal feeders, small LDFs, and capelin. The biomass was then reduced further by other changes to the model such as reduction of redfish and small silver hake biomass – see below.

The main predators of shrimp are small silver hake, sand lance, redfish, capelin and small pelagics.

Large zooplankton

If the EE is set to 0.95, the model estimates a biomass of 64 t·km^{-2}, which is too high. In order to reduce this, large zooplankton was reduced in the diets of its main predators, cetaceans, silver hake, skates, pollock, large demersal feeders and large zooplankton.

Small demersals

In order to make the biomass difference between the 1980-1985 and 1995-2000 models consistent with the difference shown by the RV trawl survey, the biomass required in the 1980-1985 model was multiplied by the difference in the RV trawl survey biomass estimates for the two time periods. This produced a biomass estimate of 0.78 t·km^{-2}. In addition, small demersals were reduced in the diets of their main predators, grey seals, redfish, cod, large demersal feeders and small large demersal feeders and the P/B was increased from 0.5 to 0.65 yr^{-1}.

Squid

Squid was reduced in the diets of its main predators, cetaceans, transient pelagics and squid. Most of this was attributed to import (ie, it was assumed that these predators fed on squid when they were in deeper waters off the shelf edge and outside the model area.). The ecotrophic efficiency was then set the default value of 0.95 and the biomass estimated by the model. We have little knowledge about biomass of squid, so little to constrain these estimates.

Transient pelagics

Cannibalism was reduced to 0.05%, and the ecotrophic efficiency set to the default of 0.95, then the biomass estimated by the model. Note that the catch comprises 91% of the mortality on this group, so the biomass estimate is sensitive to the catch estimate.

Haddock

Haddock was reduced in the diets of its main predators, silver hake, demersal piscivores and squid. In addition, the P/B was increased from 0.51 to 0.55 yr^{-1}, which is within the bounds of likely uncertainty. This reduced the ecotrophic efficiency to less than 1.

American plaice

American plaice was reduced in the diets of its main predators, grey seals, large cod and small large demersal feeders. This had the effect of reducing the ecotrophic efficiency to less than 1.

Pollock

Pollock was reduced in the diets of the following predators: squid, small silver hake, large cod and small large demersal feeders. This reduced the mortality on pollock and thus EE to less than 1.

Transient Mackerel

Transient mackerel were reduced in the diets of cetaceans and grey seals. This reduced the mortality on transient mackerel and thus EE to less than 1.

Large Demersal Feeders

Large demersal feeders were reduced in the diets of cetaceans, demersal piscivores and transient pelagics. The biomass was then adjusted slightly upwards in order to reduce EE to less than 1.

Table 56. Initial Parameter estimates, 1995-2000 (Model estimates are in italics).

Group name	Trophic level	Biomass	P/B yr^{-1}	Q/B yr^{-1}	EE	P/Q	Production/ respiration
1 Ceteaceans	*3.93*	0.260	0.040	10.170	*0*	*0.004*	*0.005*
2 Grey Seals	*4.46*	0.142	0.124	11.800	*0.965*	*0.011*	*0.013*
3 Seabirds	*3.79*	0.012	0.250	132.500	*0.662*	*0.002*	*0.002*
4 Large Cod	*4.05*	0.073	1.040	1.950	*0.059*	*0.533*	*2.000*
5 Small Cod	*3.64*	0.095	2.200	5.000	*0.717*	*0.440*	*1.222*
6 Large Silver hake	*4.1*	0.490	0.934	5.510	*0.157*	*0.170*	*0.269*
7 Small Silver Hake	*3.58*	3.710	1.069	5.800	*0.206*	*0.184*	*0.300*
8 Haddock	*3.26*	0.495	0.510	5.190	*1.326*	*0.098*	*0.140*
9 American plaice	*3.46*	0.604	0.210	1.200	*1.109*	*0.175*	*0.280*
10 Large Halibut	*4.32*	0.011	0.500	*3.333*	*0.588*	0.150	*0.231*
11 Small Halibut	*4.04*	0.101	0.460	2.750	*0.151*	*0.167*	*0.264*
12 Flounders	*3.27*	0.668	0.310	2.700	*0.824*	*0.115*	*0.168*
13 Skates	*3.47*	0.098	0.200	1.880	*2.982*	*0.106*	*0.142*
14 Dogfish	*4.08*	0.105	0.210	2.600	*0.065*	*0.081*	*0.112*
15 Redfish	*3.44*	2.556	0.222	6.130	*1.047*	*0.036*	*0.047*
16 Pollock	*3.83*	0.442	0.306	3.590	*2.288*	*0.085*	*0.119*
17 Transient Mackerel	*3.38*	0.214	0.290	2.200	*1.633*	*0.132*	*0.197*
18 Large Demersal Piscivores	*4.3*	0.048	0.363	4.220	*0.746*	*0.086*	*0.120*
19 Small Demersal Piscivores	*3.99*	0.078	*0.780*	5.200	*0.217*	0.150	*0.231*
20 Large Demersal Feeders	*3.47*	0.043	0.274	*1.827*	*2.360*	0.150	*0.231*
21 Small Large Demersal Feeders	*3.36*	0.087	*0.600*	4.000	*1.481*	0.150	*0.231*
22 Small Demersal Feeders	*3.82*	0.119	0.500	4.270	*5.894*	*0.117*	*0.171*
23 Capelin	*3.35*	2.900	*1.002*	6.680	*0.869*	0.150	*0.231*
24 Sand lance	*3.35*	22.380	0.620	4.070	*0.337*	*0.152*	*0.235*
25 Transient Pelagics	*4.8*	0.009	0.240	4.000	*4.860*	*0.060*	*0.081*
26 Small Pelagics	*3.21*	17.100	0.468	4.600	*0.129*	*0.102*	*0.146*
27 Small mesopelagics	*3.38*	*0.484*	1.400	5.000	0.950	0.280	*0.538*
28 Squid	*4.25*	0.040	*0.668*	4.450	*29.067*	0.150	*0.231*
29 Large Crabs	*3.03*	0.308	0.160	1.200	*0.882*	*0.133*	*0.200*
30 Small Crabs	*2.97*	3.780	0.300	1.500	*0.136*	*0.200*	*0.333*
31 Shrimp	*2.44*	0.201	1.700	*11.333*	*134.342*	0.150	*0.231*
32 Echinoderms	*2*	63.700	0.600	*6.667*	*0.041*	0.090	*0.127*
33 Polychaetes	*2*	11.900	2.000	*22.222*	*0.370*	0.090	*0.127*
34 Bivalve Molluscs	*2*	57.400	0.700	*7.778*	*0.006*	0.090	*0.127*
35 Other Benthic Invertebrates	*2*	4.900	2.500	*12.500*	*1.069*	0.200	*0.333*
36 Large Zooplankton	*2.45*	9.000	3.040	19.500	*4.792*	*0.156*	*0.242*
37 Small Zooplankton	*2*	34.000	8.400	*28.000*	*0.393*	0.300	*0.600*
38 Phytoplankton	*1*	43.563	52.198	-	*0.669*	-	-
39 Detritus	*1*	187.000	-	-	*0.716*	-	-

Small Large Demersal Feeders

Small large demersal feeders were reduced in the diets of small demersal piscivores, small demersals and squid. The biomass was then adjusted upwards in order to reduce EE to less than 1.

Redfish

Redfish input biomass is a q-adjusted biomass estimate, which, like the sand lance biomass estimate, is quite uncertain. In the 1980-1985 model, redfish biomass had to be reduced in order to reduce consumption of, and mortality on shrimp and large zooplankton. The same situation occurred in the 1995-2000 model, indicating that the q-adjusted estimate is too high, even though the EE is greater than 1. Mortality on redfish was reduced mainly by reducing redfish in the diet of sand lance by 50% (note that sand lance biomass was also reduced, see above). In addition, redfish were reduced in the grey seal, silver hake, haddock and pollock diet. A biomass input value of 1.4 t·km^{-2} was based on the biomass required for the 1980-1985 model, multiplied by the differences between the 1980-1985 and 1995-2000 q-adjusted biomass estimates.

Note, that Q/B of redfish was also reduced (see below) thus reducing the consumption of their prey.

Skates

Skates were reduced in the diets of grey seals. Skates comprised almost 6% of the diet estimated using fatty acid analysis, but did not appear in the fecal stomachs (although skate were present in the stomachs of seals collected in the 1980s).

Other benthic invertebrates

The ecotrophic efficiency of the other benthic invertebrates was reduced due to other changes in the model, notably the reduction of small pelagic and redfish biomass (see below).

Groups with large biomass estimates

Silver hake

Large silver hake biomass was estimated from q-adjusted RV trawl survey data. However, the estimated ecotrophic efficiency is very low, particularly for a commercial species. There is also a SPA estimate of 49779 t. of large silver hake biomass, which is approximately equal to the q-adjusted estimated. However, the SPA estimate does not include the years 1999 and 2000, nor is it adjusted for seasonality. In the 1980-1985 time period, there was not much seasonal difference in silver hake biomass in the Spring, Summer and Fall Surveys. In the 1995-2000 time period however, Spring biomass is lower than the summer biomass. When both these factors were taken into account, the SPA biomass estimate was reduced to 33682 t., or 0.329 t·km^{-2}. This value was used in the model, increasing the EE to 0.316 (from 0.156).

Small silver hake, sand lance and small pelagics

These groups cause high mortality on shrimp and large zooplankton and thus raising their biomass estimates to values considered unreasonable. In addition, the EE of all these groups is very low. In order to reduce the biomass of shrimp and large zooplankton, the biomass of these predator groups were reduced.

Small silver hake

As with the large silver hake, biomass was estimated from q-adjusted biomass estimates, and these can only be considered ball park figures. The biomass estimate was reduced by 40% to 228185 (0.23 t·km^{-2}), from 379626 (0.37 t·km^{-2}).

Sand lance

The range of possible biomass estimates is large (7.3 – 22.4 t·km^{-2}), due to the uncertainty associated with the trawl survey estimates and the application of a constant catchability across all sizes and through time (Table 32). The input biomass estimate of 22.4 t·km^{-2} was considered to be at the top end of the range. The catchability that is implied by the sand lance biomass estimate from the 1980-1985 model is 0.0005. The 1995-2000 biomass estimate of 22.4 t·km^{-2} assumed that catchability had increased to 0.005. Here it is assumed that catchability increased 20 fold to 0.01, reducing the biomass estimate of 11.2 t·km^{-2} (1,146,040 t.). Given the uncertainty associated with the estimation of sand lance biomass, this is reasonable.

Small Pelagics

As with the sand lance, there is large uncertainty associated with the trawl survey estimates of small pelagic biomass and the catchability used to adjust this estimate. A catchability of 0.025 from the English Groundfish Survey (Harley et al. 2001) was used for the input estimate. However, the consequent biomass estimate is large, with a very low estimated EE. Such a low EE is unlikely for a forage species such as herring. In order to obtain a more realistic estimate of small pelagic biomass, it was assumed that the catchability was 0.05, producing a biomass estimate of 8.4 t·km^{-2}, 869,762 t.

P/Q too high or too low

The production/consumption ratio should be between 0.1 and 0.3 for most species (Christensen and Pauly 1992).

The following functional groups had P/Q values less than 0.1 (Table 57):

- Haddock Q/B was estimated from empirical data for the eastern Scotian Shelf. There is a lower estimate of 3.0 yr^{-1} for haddock Q/B from Georges Bank (Pauly 1989). It is assumed here that Q/B is midway between these two estimates, ie, Q/B=4 yr^{-1}.
- Spiny dogfish Q/B was reduced from 2.6 yr^{-1} to 2 yr^{-1}, which is within the likely range of uncertainty of this parameter.
- Redfish Q/B was estimated as 6.13 yr^{-1} from consumption studies on the eastern Scotian Shelf. However, estimates from an earlier study by Dolgov and Drevetnyak (1990) were considerably lower than this. The value of 2 yr^{-1}, derived from these estimates by Bundy et al. (2000) was used.
- Pollock and demersal piscivores Q/B was estimated from consumption studies on the eastern Scotian Shelf. Both were reduced to 3.0 yr^{-1}, which is within the likely range of uncertainty.
- Transient pelagics Q/B was the average of values in the literature for areas other than the eastern Scotian Shelf. It produced a very low P/Q of 0.06, although it is within the range described above. However, Q/B was reduced by 50% to 2 yr^{-1}.

Table 57. Original and adjusted values of Q/B and P/Q (1995-2000 model).

	Original Q/B	Adjusted Q/B	Original P/Q	Balanced P/Q
Haddock	5.19	4.0	0.098	0.137
Spiny dogfish	2.60	2.0	0.081	0.105
Redfish	6.13	2.0	0.036	0.150
Pollock	3.59	3.0	0.085	0.102
Dem. Piscivores	4.22	3.0	0.086	0.121
Trans. Pels	4.00	2.0	0.060	0.120

Large cod and small cod had a P/Q greater than 0.3 and a production/respiration ratio greater than 1. Thermodynamic constraints limit the production/respiration ratio to less than 1 (Christensen et al. 2000). Respiration is used in Ecopath to balance flows within groups (Equation 3) and is essentially the difference between food that is assimilated (consumption) and production. A default assimilation efficiency of 0.8 is used for all groups in the model. The P/B ratio for both cod groups is high, 1.04 yr^{-1} for large cod and 2.2 yr^{-1} for small cod, and this is where the problem lies. The consumption estimates were derived from consumption studies of stomach data collected from the eastern Scotian Shelf, and are comparable to estimates in the literature. The P/B estimate for large cod was derived from estimates of total mortality (using Paloheimo's method), assuming P/B=Z and the estimate for small cod was derived from estimates of production from a SPA, divided by SPA biomass. It was noted that the latter is an over estimate of mortality because it includes the loss of small cod that grow to become large cod.

Given that in Ecopath such high estimates produce thermodynamically impossible ratios, both estimates were reduced *ad hoc*. Large cod P/B was reduced to 0.5 yr^{-1}, giving a P/Q=0.256 and P/R=0.472. Small cod P/B was reduced to 1.4, producing a P/Q=0.280 and P/R=0.538 (Table 58). Fanning et al. (2003) estimated an average Z of 0.7 for age 2 to 4 year old cod for 1995-2000. Given that this includes negative values (which are artefacts of the sampling method) and does not include age 1 cod, the value of 1.4 yr^{-1} for small cod may be reasonable.

Table 58. Initial and final estimates of large and small cod P/B (yr^{-1}), Q/B (yr^{-1}) and P/R.

	Input estimates			Output estimates		
	P/B	P/Q	P/R	P/B	P/Q	P/R
Large cod	1.04	0.533	2.000	0.500	0.256	0.472
Small cod	2.20	0.440	1.222	1.400	0.280	0.538

Other changes to input parameters

Seabirds

The respiration/biomass ratio is greater than 100 and is much higher than any of the R/B ratios for the other groups (Table 58). Whilst seabirds do use a lot of energy, and thus have a high respiration, this was considered unrealistic. In order to reduce the R/B, the Q/B was reduced from 132 yr^{-1} to 55 yr^{-1}. This is consistent with empirical values described for seabirds in the Gulf of St. Lawrence (Morissette et al. 2003). This reduced the R/B to 44 yr^{-1}.

Small zooplankton

As a consequence of the changes described above and further diet changes below, the EE of the small zooplankton increased to a value greater than 1. In order to reduce this, biomass was increased to 0.44 $t \cdot km^{-2}$ (from 0.34 $t \cdot km^{-2}$).

Other changes to diets

Cetaceans

As a consequence of the reduction of squid, transient mackerel and large demersal feeders in the cetacean diets, sand lance and small zooplankton were increased. In addition, small cod was reduced.

Grey seals

Skates and small demersals were reduced in the diet of grey seals. In order for the total prey items in the diet to sum to 1, more sand lance and capelin were added in the grey seal diet.

Large Demersal piscivores

Large demersal feeders were reduced in the diet of large demersal piscivores. In order for the total prey items in the diet to sum to 1, more sand lance was added in the large demersal piscivores diet.

Small demersal piscivores

Small large demersal feeders were reduced in the diet of small demersal piscivores. In order for the total prey items in the diet to sum to 1, more sand lance was added in the small demersal piscivores diet.

Large and small large demersal feeders

Small large demersal feeders are more piscivorous than large demersal feeders (Tables 20 and 21 in Appendix 2). This is unlikely and is probably due to the small sample sizes (n=136 (small large demersal feeders), n= 64 (large demersal feeders). In order to make this more representative, it was assumed that the proportion of fish in the large demersal feeders diet was the same as that seen in the small large demersal feeders diet. The fish in the small large demersal feeders diet was then reduced by 50%. Differences were attributed to the invertebrate species.

Small demersals

Small large demersal feeders were reduced in the diet of small demersals. In order for the total prey items in the diet to sum to 1, more sand lance was added in the small demersal diet.

Capelin

Shrimp were reduced in the diet of small demersals. In order for the total prey items in the diet to sum to 1, more small zooplankton was added in the small demersal diet.

Large pelagics

Several changes were made to the large pelagics diet. Seabirds, squid and cannibalism were reduced and the difference put to import. In addition, large demersal feeders were distributed over pollock, small large demersal feeders and large demersal feeders. Demersal piscivores were re-distributed as large (20%) and small (80%) demersal piscivores.

Squid

Squid imposed high predation mortality on many groups in the model. In order to reduce this, several changes were made to the diet. Small large demersal feeders were reduced by 83 %, 90% of mesopelagics and all of squid cannibalism were treated as import. This was insufficient to correct the problems in the model so all groups were reduced by 50%, except large zooplankton, which was unchanged, and small zooplankton which was increased 3 fold. The difference was treated as import.

Large zooplankton

The large zooplankton - cannibalism was reduced, consumption of detritus was reduced and consumption of small zooplankton increased.

CONSISTENCY BETWEEN THE TWO MODELS

Once the two models were balanced, their diets were compared in order to ensure that any species that occurred in the diet in the 1980-1985 time period should also be present in the 1995-2000 time period. Since the diets for each time period came from two different sources, and since the diets for 1980-1985 came from a range of sources, there were many cases where species were only present in one time period. Less than 1% of the prey item is added to the diet by multiplying the 1980-1985 or 1995-2000 value by 1,1/10 or 1/100. The diet is then normalised.

The final diets used in the two models are given in Tables 59 and 60.

Table 59. Final Diet Input for 1980-1985 model.

Input	1	2	3	4	5	6	7	8	9	10	11	12	13
Prey \ Predator	Cetea	Seals	Birds	L.Cod	S.Cod	L.Shak	S.Shak	Hadd	A.plaice	L.Hal	S.Hal	Flats	Skates
1 Cetea													
2 Seals													
3 Birds			0.001										
4 L.Cod		0.018											
5 S.Cod	0.013	0.166	0.005	0.017	0.006	0.001		0.009		0.031			0.050
6 L.Shak		0.027				0.013							
7 S.Shak	0.008	0.140		0.098	0.004	0.073	0.015	0.009	0.006	0.063	0.003		0.005
8 Hadd		0.092	0.005	0.012		0.001	0.000	0.009		0.094	0.005		
9 A.plaice		0.035		0.003	0.000			0.001	0.001	0.131	0.016		
10 L.Hal													
11 S.Hal		0.001		0.001									
12 Flats		0.020		0.005				0.001	0.000	0.031	0.007		0.001
13 Skates		0.037								0.028			0.001
14 Dogfish													
15 Redfish	0.005	0.052		0.012	0.003	0.001		0.004	0.000		0.003	0.007	0.011
16 Pollock		0.003		0.017	0.005	0.012	0.001						
17 T.Mack.	0.039	0.016											0.001
18 LDPisc	0.002	0.000		0.004									
19 SDPisc	0.002	0.002		0.013	0.000					0.063			
20 LDF	0.002	0.001		0.005									
21 SLDF	0.002	0.009		0.012	0.001			0.000	0.000	0.031	0.018		0.042
22 SDFs		0.030	0.008	0.009	0.002	0.001	0.000	0.005	0.000		0.020	0.000	0.075
23 Cap		0.000		0.000	0.002	0.000	0.000		0.001		0.002	0.000	0.004
24 Slance	0.075	0.111	0.064	0.108	0.024	0.017	0.004	0.060	0.001	0.250	0.273	0.001	0.005
25 T.Pels													
26 S.Pels	0.040	0.058	0.046	0.025	0.003	0.012	0.004	0.001	0.000	0.088	0.002		0.003
27 Mesop			0.008			0.042	0.021	0.000					
28 Squid	0.005	0.033	0.010	0.009	0.001	0.010	0.001	0.002	0.000	0.031	0.019		0.039
29 LCrab				0.001	0.000			0.000					0.002
30 SCrab		0.033	0.015	0.057	0.014		0.000	0.007	0.028	0.063	0.143	0.005	0.119
31 Shrimp		0.001	0.015	0.085	0.113	0.009	0.040	0.029	0.029	0.094	0.309	0.083	0.059
32 Echin			0.015	0.027	0.020			0.422	0.795	0.003	0.007	0.052	0.000
33 Polyc		0.021	0.015	0.032	0.057			0.098	0.028		0.018	0.622	0.430
34 Moll		0.021	0.015	0.070	0.048			0.046	0.046		0.007	0.015	0.076
35 OBI		0.074	0.015	0.100	0.170	0.097	0.008	0.075	0.017			0.047	0.024
36 LZP	0.605		0.432	0.266	0.507	0.401	0.808	0.183	0.047		0.148	0.169	0.038
37 SZP	0.082			0.012	0.019	0.001	0.001	0.037					0.016
38 PHYP													
39 DET			0.165										
40 Import	0.120		0.165			0.309	0.098						
41 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 59 (cont.). Diet Input for 1980-1985 model.

Input	14	15	16	17	18	19	20	21	22	23	24	25	26
Prey \ Predator	Dogfish	Redfish	Pollock	T.Mack.	LDPisc	SDPisc	LDF	SLDF	SDFs	Cap	Slance	T.Pels	S.Pels
1 Cetea													
2 Seals													
3 Birds												0.001	
4 L.Cod	0.005				0.009								
5 S.Cod	0.021		0.001		0.057	0.081	0.005	0.012	0.000				
6 L.Shak	0.011				0.011							0.069	
7 S.Shak	0.043		0.109		0.483	0.201	0.047		0.002			0.012	
8 Hadd			0.010		0.042	0.028	0.027						
9 A.plaice	0.107				0.019	0.024	0.005	0.020					
10 L.Hal													
11 S.Hal					0.001								
12 Flats	0.043		0.000		0.016	0.091			0.000			0.041	
13 Skates					0.019		0.002					0.007	
14 Dogfish					0.003							0.029	
15 Redfish			0.015		0.097	0.040	0.071	0.001	0.000		0.001	0.060	
16 Pollock			0.001		0.025	0.001	0.002	0.002	0.000			0.006	
17 T.Mack.	0.063				0.004							0.148	
18 LDPisc	0.002				0.003							0.003	
19 SDPisc	0.009				0.024							0.012	
20 LDF	0.011				0.001	0.005						0.012	
21 SLDF	0.043				0.038	0.027	0.018		0.001			0.041	
22 SDFs	0.026				0.017	0.009	0.001	0.005	0.012				
23 Cap									0.000	0.010		0.010	
24 Slance	0.010		0.050		0.001	0.004	0.043		0.013	0.010		0.001	
25 T.Pels												0.005	
26 S.Pels	0.031		0.020	0.083	0.048	0.005	0.007		0.004			0.080	
27 Mesop	0.001		0.019									0.029	
28 Squid	0.093		0.007		0.012	0.049	0.022		0.000				
29 LCrab					0.000	0.008	0.002		0.000			0.005	
30 SCrab	0.019		0.001		0.000	0.013	0.043	0.019	0.027				
31 Shrimp	0.017	0.279	0.031	0.028	0.062	0.310	0.083	0.158	0.050	0.001	0.000		0.046
32 Echin						0.000	0.268	0.045	0.090		0.005		
33 Polyc	0.008		0.011			0.011	0.007	0.359	0.188	0.001			
34 Moll	0.033					0.000	0.167	0.060	0.008				
35 OBI	0.111	0.008	0.028		0.007	0.048	0.055	0.035	0.477		0.039	0.005	0.100
36 LZP	0.280	0.673	0.676	0.585	0.001	0.044	0.115	0.284	0.076	0.434	0.208	0.005	0.513
37 SZP	0.013	0.040	0.023	0.304			0.011		0.051	0.544	0.708		0.341
38 PHYP									0.000				
39 DET							0.001				0.040		
40 Import												0.418	
41 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 59 (cont.) Diet Input for 1980-1985 model.

Input	27	28	29	30	31	32	33	34	35	36	37
Prey \ Predator	Mesop	Squid	LCrab	SCrab	Shrimp	Echin	Polyc	Moll	OBI	LZP	SZP
1 Cetea											
2 Seals											
3 Birds											
4 L.Cod											
5 S.Cod		0.007									
6 L.Shak											
7 S.Shak		0.048									
8 Hadd		0.007									
9 A.plaice											
10 L.Hal											
11 S.Hal											
12 Flats											
13 Skates											
14 Dogfish											
15 Redfish											
16 Pollock		0.007									
17 T.Mack.											
18 LDPisc											
19 SDPisc		0.007									
20 LDF											
21 SLDF		0.005									
22 SDFs											
23 Cap	0.001										
24 Slance											
25 T.Pels											
26 S.Pels											
27 Mesop	0.050	0.007									
28 Squid	0.040										
29 LCrab											
30 SCrab		0.012	0.025								
31 Shrimp			0.085								
32 Echin			0.243	0.153							
33 Polyc			0.108	0.144	0.015						
34 Moll			0.007	0.012							
35 OBI			0.284	0.435	0.015						
36 LZP	0.459	0.358	0.148	0.157	0.120					0.020	
37 SZP	0.450	0.200			0.240					0.430	
38 PHYP					0.085			0.500		0.370	1.000
39 DET			0.100	0.100	0.525	1.000	1.000	0.500	1.000	0.180	
40 Import		0.343									
41 Sum	1	1	1	1	1	1	1	1	1	1	1

Table 60. Final Diet Input for 1995-2000 model.

Input	1	2	3	4	5	6	7	8	9	10	11	12	13
Prey \ Predator	Cetea	Seals	Birds	L.Cod	S.Cod	L.Shak	S.Shak	Hadd	A.plaice	L.Hal	S.Hal	Flats	Skates
1 Cetea													
2 Seals													
3 Birds			0.001										
4 L.Cod		0.001											
5 S.Cod	0.006	0.014	0.005	0.080	0.002	0.010		0.001		0.031			0.000
6 L.Shak		0.005				0.012							
7 S.Shak	0.007	0.027		0.007	0.002	0.054	0.012	0.001	0.006	0.063	0.003		0.003
8 Hadd		0.004	0.005	0.004		0.055	0.000	0.001		0.094	0.001		
9 A.plaice		0.030		0.108	0.000			0.000	0.001	0.131	0.008		
10 L.Hal													
11 S.Hal		0.000											
12 Flats		0.052		0.009				0.000	0.001	0.031	0.025		0.001
13 Skates		0.004								0.028			0.001
14 Dogfish													
15 Redfish	0.004	0.051		0.004	0.005	0.001		0.027	0.000		0.026	0.007	0.002
16 Pollock		0.003		0.020	0.009	0.007	0.005						
17 T.Mack.	0.010	0.001											0.001
18 LDPisc	0.002	0.000		0.000									
19 SDPisc	0.002	0.002		0.001	0.000					0.063			
20 LDF	0.001	0.001		0.000									
21 SLDF	0.002	0.008		0.003	0.001			0.000	0.001	0.031	0.012		0.002
22 SDFs		0.029	0.008	0.004	0.006	0.001	0.002	0.001	0.001		0.021	0.000	0.000
23 Cap		0.221		0.004	0.014	0.343	0.017		0.068		0.242	0.002	0.004
24 Slance	0.189	0.459	0.277	0.220	0.154	0.139	0.091	0.053	0.108	0.250	0.286	0.052	0.099
25 T.Pels													
26 S.Pels	0.035	0.008	0.092	0.140	0.045	0.069	0.003	0.009	0.000	0.088	0.015		0.004
27 Mesop			0.008			0.039	0.021	0.000					
28 Squid	0.005	0.042	0.010	0.005	0.001	0.009	0.002	0.002	0.001	0.031	0.005		0.001
29 LCrab				0.001	0.005			0.000					0.002
30 SCrab		0.032	0.015	0.018	0.028		0.000	0.008	0.013	0.063	0.003	0.001	0.053
31 Shrimp		0.000	0.015	0.276	0.299	0.046	0.572	0.029	0.187	0.094	0.195	0.028	0.085
32 Echin			0.015	0.026	0.000			0.024	0.042	0.003	0.007	0.001	0.000
33 Polyc		0.001	0.015	0.013	0.034			0.441	0.208		0.001	0.418	0.141
34 Moll		0.001	0.015	0.001	0.000			0.009	0.013		0.007	0.007	0.000
35 OBI		0.001	0.015	0.012	0.062	0.000	0.003	0.109	0.117			0.091	0.108
36 LZP	0.586		0.432	0.028	0.332	0.213	0.269	0.249	0.232		0.145	0.394	0.475
37 SZP	0.036			0.011	0.001	0.001	0.001	0.037					0.016
38 PHYP													
39 DET			0.016										
40 Import	0.115		0.056										
41 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 60(cont.) Diet Input for 1995-2000 model.

Input	14	15	16	17	18	19	20	21	22	23	24	25	26
Prey \ Predator	Dogfish	Redfish	Pollock	T.Mack.	LDPisc	SDPisc	LDF	SLDF	SDFs	Cap	Slance	T.Pels	S.Pels
1 Cetea													
2 Seals													
3 Birds												0.001	
4 L.Cod	0.000				0.001								
5 S.Cod	0.005		0.001		0.021	0.054	0.023	0.012	0.001				
6 L.Shak	0.001				0.000							0.067	
7 S.Shak	0.197		0.029		0.130	0.060	0.004		0.015			0.012	
8 Hadd	0.016		0.062		0.179	0.030	0.003						
9 A.plaice	0.140				0.002	0.026	0.019	0.010					
10 L.Hal													
11 S.Hal					0.001								
12 Flats	0.006		0.000		0.091	0.097			0.007			0.040	
13 Skates					0.002		0.002					0.007	
14 Dogfish					0.000							0.028	
15 Redfish	0.013	0.002	0.084		0.016	0.042	0.001	0.001	0.005		0.001	0.058	
16 Pollock			0.001		0.001	0.001	0.002	0.001	0.001			0.006	
17 T.Mack.	0.001				0.000							0.144	
18 LDPisc	0.000				0.000							0.003	
19 SDPisc	0.001				0.002							0.011	
20 LDF	0.000				0.010	0.005						0.011	
21 SLDF	0.000				0.037	0.028	0.002		0.003			0.040	
22 SDFs	0.000	0.003			0.013	0.010	0.018	0.009	0.003				
23 Cap									0.003	0.025		0.040	
24 Slance	0.038	0.004	0.051		0.109	0.073	0.047		0.386	0.010		0.001	
25 T.Pels												0.005	
26 S.Pels	0.261		0.154	0.083	0.170	0.058	0.007		0.001			0.078	
27 Mesop	0.001	0.031	0.002									0.028	
28 Squid	0.040	0.004	0.024		0.078	0.053	0.021		0.002				
29 LCrab					0.001	0.009	0.009		0.000			0.005	
30 SCrab	0.002		0.005		0.003	0.014	0.120	0.033	0.041				
31 Shrimp	0.091	0.568	0.149	0.028	0.123	0.331	0.263	0.269	0.091	0.181	0.134		0.046
32 Echin						0.000	0.083	0.038	0.009		0.006		
33 Polyc	0.001	0.000	0.000			0.012	0.128	0.305	0.043	0.293			
34 Moll	0.003					0.001	0.013	0.051	0.001				
35 OBI	0.177	0.117	0.010		0.009	0.051	0.135	0.030	0.026		0.000	0.005	0.100
36 LZP	0.002	0.266	0.406	0.585	0.001	0.046	0.090	0.241	0.359	0.309	0.722	0.005	0.411
37 SZP	0.001	0.004	0.021	0.304			0.010		0.000	0.181	0.097		0.443
38 PHYP									0.004				
39 DET							0.001				0.040		
40 Import												0.405	
41 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 60 (cont.). Diet Input for 1995-2000 model.

Input	27	28	29	30	31	32	33	34	35	36	37
Prey \ Predator	Mesop	Squid	LCrab	SCrab	Shrimp	Echin	Polyc	Moll	OBI	LZP	SZP
1 Cetea											
2 Seals											
3 Birds											
4 L.Cod											
5 S.Cod		0.007									
6 L.Shak											
7 S.Shak		0.048									
8 Hadd		0.007									
9 A.plaice											
10 L.Hal											
11 S.Hal											
12 Flats											
13 Skates											
14 Dogfish											
15 Redfish											
16 Pollock		0.007									
17 T.Mack.											
18 LDPisc											
19 SDPisc		0.007									
20 LDF											
21 SLDF		0.005									
22 SDFs											
23 Cap	0.010										
24 Slance											
25 T.Pels											
26 S.Pels											
27 Mesop	0.050	0.007									
28 Squid	0.040										
29 LCrab											
30 SCrab		0.012	0.025								
31 Shrimp			0.085								
32 Echin			0.243	0.153							
33 Polyc			0.108	0.144	0.015						
34 Moll			0.007	0.012							
35 OBI			0.284	0.435	0.015						
36 LZP	0.450	0.358	0.148	0.157	0.120					0.020	
37 SZP	0.450	0.200			0.240					0.430	
38 PHYP					0.085			0.500		0.370	1.000
39 DET			0.100	0.100	0.525	1.000	1.000	0.500	1.000	0.180	
40 Import		0.343									
41 Sum	1	1	1	1	1	1	1	1	1	1	1

BALANCED MODEL RESULTS

The basic estimates from the two balanced Ecopath models are given in Tables 61 and 62.

Table 61. Ecopath estimates from the 1980-1985 model. Estimated parameters are in italics.

Group name	Trophic level	Biomass t.km^{-2}	P/B Yr^{-1}	Q/B Yr^{-1}	EE	P/Q	R/B
1 Ceteaceans	3.59	0.230	0.040	10.170	*0*	*0.004*	*8.096*
2 Grey Seals	4.16	0.025	0.124	11.800	*0.710*	*0.011*	*9.316*
3 Seabirds	3.27	0.012	0.250	55.000	*0.244*	*0.005*	*43.750*
4 Large Cod	3.68	1.218	0.631	2.100	*0.675*	*0.300*	*1.049*
5 Small Cod	3.36	0.756	0.750	5.020	*0.981*	*0.149*	*3.266*
6 Large Silver hake	3.63	0.799	1.153	7.420	*0.558*	*0.155*	*4.783*
7 Small Silver Hake	3.49	2.132	1.017	7.773	*0.950*	*0.131*	*5.201*
8 Haddock	3.22	0.840	0.450	4.000	*0.886*	*0.113*	*2.750*
9 American plaice	3.08	1.077	0.250	1.200	*0.571*	*0.208*	*0.710*
10 Large Halibut	4.15	0.054	0.230	*1.533*	*0.681*	0.150	*0.997*
11 Small Halibut	3.75	0.016	0.460	2.750	*0.640*	*0.167*	*1.740*
12 Flounders	3.13	0.652	0.341	2.700	*0.584*	*0.126*	*1.819*
13 Skates	3.46	0.274	0.200	1.880	*0.655*	*0.106*	*1.304*
14 Dogfish	3.83	0.241	0.230	2.000	*0.135*	*0.115*	*1.370*
15 Redfish	3.43	3.400	0.242	2.000	*0.394*	*0.121*	*1.358*
16 Pollock	3.64	0.976	0.350	3.000	*0.937*	*0.117*	*2.050*
17 Transient Mackerel	3.39	0.592	0.290	2.200	*0.852*	*0.132*	*1.470*
18 Large Demersal Piscivores	4.37	0.199	0.301	3.000	*0.554*	*0.100*	*2.099*
19 Small Demersal Piscivores	3.95	*0.113*	*0.780*	5.200	0.950	0.150	*3.380*
20 Large Demersal Feeders	3.47	*0.104*	0.344	*2.293*	0.950	0.150	*1.491*
21 Small Large Demersal Feeders	3.27	*0.223*	0.700	*4.667*	0.950	0.150	*3.033*
22 Small Demersal Feeders	3.12	*0.260*	0.650	4.270	0.950	0.152	*2.766*
23 Capelin	3.22	0.028	*0.700*	4.667	*0.917*	0.150	*3.033*
24 Sand lance	3.06	1.104	1.150	*7.667*	0.950	0.150	*4.983*
25 Transient Pelagics	4.38	0.046	0.240	2.000	*0.390*	*0.120*	*1.360*
26 Small Pelagics	3.26	*1.215*	0.510	4.590	0.950	*0.111*	*3.162*
27 Small mesopelagics	3.34	*0.630*	1.400	5.000	0.950	*0.280*	*2.600*
28 Squid	3.46	*0.656*	*0.668*	4.450	0.950	0.150	*2.893*
29 Large Crabs	3.03	0.150	0.160	1.200	*0.511*	*0.133*	*0.800*
30 Small Crabs	2.97	*1.687*	0.300	1.500	0.950	*0.200*	*0.900*
31 Shrimp	2.45	*2.767*	1.700	*11.300*	0.950	0.150	*7.340*
32 Echinoderms	2	63.700	0.600	*6.700*	*0.088*	0.090	*4.760*
33 Polychaetes	2	11.900	2.000	*27.800*	*0.146*	0.072	*20.240*
34 Bivalve Molluscs	2	57.400	0.700	*7.778*	*0.020*	0.090	*5.522*
35 Other Benthic Invertebrates	2	4.900	2.500	*12.500*	*0.433*	0.200	*7.500*
36 Large Zooplankton	2.46	*16.131*	3.040	19.500	0.950	*0.156*	*12.560*
37 Small zooplankton	2	34.000	8.400	*28.000*	*0.539*	0.300	*14.000*
38 Phytoplankton	1	34.384	80.731	-	*0.466*	-	-
39 Detritus	1	187.000	-	-	*0.496*	-	-

Table 62. Ecopath estimates from the 1995-2000 model. Estimated parameters are in italics.

Group name	Trophic level	Biomass (t.km2)	P/B	Q/B	EE	P/Q	P/R
1 Ceteaceans	3.71	0.261	0.040	10.170	*0*	0.004	*0.005*
2 Grey Seals	4.36	0.142	0.124	11.800	*0.682*	0.011	*0.013*
3 Seabirds	3.79	0.012	0.250	55.000	*0.243*	0.005	*0.006*
4 Large Cod	4.01	0.073	0.500	1.950	*0.124*	0.256	*0.472*
5 Small Cod	3.64	0.095	1.400	5.000	*0.972*	0.280	*0.538*
6 Large Silver hake	4.1	0.329	0.934	5.510	*0.316*	0.170	*0.269*
7 Small Silver Hake	3.59	2.230	1.069	5.800	*0.322*	0.184	*0.300*
8 Haddock	3.26	0.495	0.550	4.000	*0.962*	0.138	*0.208*
9 American plaice	3.45	0.604	0.210	1.200	*0.990*	0.175	*0.280*
10 Large Halibut	4.3	0.011	0.500	*3.333*	*0.588*	*0.150*	*0.231*
11 Small Halibut	4.01	0.101	0.460	2.750	*0.158*	0.167	*0.264*
12 Flounders	3.28	0.668	0.310	2.700	*0.885*	0.115	*0.168*
13 Skates	3.47	0.098	0.200	1.880	*0.940*	0.106	*0.153*
14 Dogfish	4.05	0.105	0.210	2.000	*0.139*	0.105	*0.151*
15 Redfish	3.44	1.400	0.300	2.000	*0.967*	*0.150*	*0.231*
16 Pollock	3.8	0.442	0.306	3.000	*0.928*	0.102	*0.146*
17 Transient Mackerel	3.38	0.214	0.290	2.200	*0.751*	0.132	*0.197*
18 Large Demersal Piscivores	4.24	0.048	0.363	3.000	*0.738*	0.121	*0.178*
19 Small Demersal Piscivores	3.95	0.078	*0.780*	5.200	*0.466*	*0.150*	*0.231*
20 Large Demersal Feeders	3.5	0.047	0.274	*1.827*	*0.847*	*0.150*	*0.231*
21 Small Large Demersal Feeders	3.32	0.120	0.600	*4.000*	*0.937*	*0.150*	*0.231*
22 Small Demersal Feeders	3.82	0.780	0.650	*4.270*	*0.257*	0.152	*0.235*
23 Capelin	3.27	2.900	*1.002*	6.680	*0.639*	*0.150*	*0.231*
24 Sand lance	3.35	11.200	0.620	4.070	*0.717*	0.152	*0.235*
25 Transient Pelagics	4.46	*0.046*	0.240	2.000	0.950	0.120	*0.176*
26 Small Pelagics	3.21	8.500	0.468	4.600	*0.198*	0.102	*0.146*
27 Small mesopelagics	3.35	*0.423*	1.400	5.000	0.950	0.280	*0.538*
28 Squid	3.48	*0.526*	*0.668*	4.450	0.950	*0.150*	*0.231*
29 Large Crabs	3.03	0.308	0.160	1.200	*0.899*	0.133	*0.200*
30 Small Crabs	2.97	3.780	0.300	1.500	*0.294*	0.200	*0.333*
31 Shrimp	2.45	*13.571*	1.700	*11.300*	0.950	*0.150*	*0.232*
32 Echinoderms	2	63.700	0.600	*6.700*	*0.036*	0.090	*0.126*
33 Polychaetes	2	11.900	2.000	*27.800*	*0.461*	0.072	*0.099*
34 Bivalve Molluscs	2	57.400	0.700	*7.778*	*0.006*	0.090	*0.127*
35 Other Benthic Invertebrates	2	4.900	2.500	*12.500*	*0.805*	0.200	*0.333*
36 Large Zooplankton	2.46	*34.576*	3.040	19.500	0.950	0.156	*0.242*
37 Small zooplankton	2	44.000	8.400	*28.000*	*0.957*	0.300	*0.600*
38 Phytoplankton	1	43.563	52.198	-	*0.755*	-	-
39 Detritus	1	187.000	-	-	*0.907*	-	-

Biomass

The biomass in 1980-1985 and 1995-2000 are compared in Figure 16, with confidence limits on the estimates, estimated from the uncertainty analysis. In total, the biomass of 15 groups increased between the two periods and 23 decreased. However, due to the uncertainty associated with the input parameters, only 5 groups had a significant increase and 10 groups a significant decrease (Table 63). Also shown in Table 63 are those groups whose biomass changed by more than 20% from 1980-1985 to 1995-2000. Whilst there may be a change in biomass greater than 20%, it is not significant in all cases. Clearly, there are changes in biomass of some groups for which there is so much uncertainty associated with the biomass estimates that it cannot be discerned whether the biomass change is real or not, eg., pollock, crab, shrimp, zooplankton.

Table 63. Comparison of biomass (t·km^{-2}) in 1980-1985 and 1995-2000.

	1980-1985	1995-2000	> 20 % Change	Significant?
1 Ceteaceans	0.23	0.26		
2 Grey Seals	0.03	0.14	↑	***
3 Seabirds	0.01	0.01		
4 Large Cod	1.22	0.07	↓	***
5 Small Cod	0.76	0.10	↓	***
6 Large Silver hake	0.80	0.33	↓	***
7 Small Silver Hake	2.13	2.23		
8 Haddock	0.84	0.50	↓	***
9 American plaice	1.08	0.60	↓	***
10 Large Halibut	0.05	0.01	↓	***
11 Small Halibut	0.02	0.10	↑	***
12 Flounders	0.65	0.67		
13 Skates	0.27	0.10	↓	***
14 Dogfish	0.24	0.10	↓	***
15 Redfish	3.40	1.40	↓	
16 Pollock	0.98	0.44	↓	***
17 Transient Mackerel	0.59	0.21	↓	
18 Large Demersal Piscivores	0.20	0.05	↓	***
19 Small Demersal Piscivores	0.11	0.08	↓	
20 Large Demersal Feeders	0.10	0.05	↓	
21 Small Large Demersal Feeders	0.22	0.12	↓	
22 Small Demersal Feeders	0.26	0.78	↑	***
23 Capelin	0.03	2.90	↑	***
24 Sand lance	1.10	11.20	↑	***
25 Transient Pelagics	0.05	0.05		
26 Small Pelagics	1.22	8.50	↑	***
27 Small mesopelagics	0.63	0.42	↓	
28 Squid	0.66	0.53		
29 Large Crabs	0.15	0.31	↑	
30 Small Crabs	1.69	3.78	↑	
31 Shrimp	2.77	13.57	↑	
32 Echinoderms	63.70	63.70		
33 Polychaetes	11.90	11.90		
34 Bivalve Molluscs	57.40	57.40		
35 Other Benthic Invertebrates	4.90	4.90		
36 Large Zooplankton	16.13	34.58	↑	
37 Small zooplankton	34.00	44.00	↑	
38 Phytoplankton	34.38	43.56	↑	

When these groups are aggregated (Table 64) there is an overall decrease in the biomass of demersal groundfish species and an increase in grey seals and small pelagic species. This is reflected in a change in the pelagic:demersal ratio, which is an indicator of the effects of fishing (Zwanenburg 2000, Rochet and Trenkel 2003) from 0.3 to 3.

Table 64. Comparison of biomass (t·km^{-2}) of functional groups in 1980-1985 and 1995-2000.

	1980-1985	1995-2000	% change	Significant?
Cetaceans and birds	0.24	0.27	13.13	
Grey seals	0.03	0.14	468.00	***
Demersal Fish	13.33	7.72	-42.07	***
Pelagic Fish	3.62	23.28	543.94	***
Commercial crustaceans	4.60	17.66	283.60	
Other invertebrates	138.56	138.43	-0.09	
Zooplankton	50.13	78.58	56.74	
Phytoplankton	34.38	43.56	26.69	
Total	244.89	309.65	26.44	

Consumption

Changes in consumption parallel the changes seen in biomass (Table 65). Total consumption has increased by a greater margin than total biomass (although the change in consumption is not significant). This may be due to a greater proportion of small individuals in the population in 1995-2000.

Where there are differences between changes in biomass and consumption for individual groups, these can be attributed to the greater uncertainty associated with estimates of consumption since they include uncertainty in both Q/B and biomass estimates, and thus the confidence limits are wider. Several groups such as haddock, skates and pollock, for example, had a significant decrease in biomass but not in consumption. In the case of small silver hake total consumption decreased, whereas biomass changed little: this is due to the lower consumption estimate in the 1995-2000.

When these groups are aggregated as in Table 64, (Table 66) there are large increases in consumption of three groups, grey seals, pelagic fish and commercial crustaceans (not significant). The consumption by demersal fish decreased, but it is not significant. Again, these changes mirror the changes observed for biomass.

Trophic Level and Increase in Piscivory

The average trophic level of many groups has increased from 1980-1985 to 1995-2000 (Figure 17), although groups at the lower trophic levels, such as the invertebrates, squid and mesopelagics show no change.

This increase in trophic level may indicate an increase in piscivory, an increase in the consumption of prey with increased trophic level such as small demersals and sand lance, or both. In order to disentangle these effects, the diets of the eight groups with significant increases in their trophic level were examined for relative changes in the proportion of small demersals, sand lance, fish and other prey species (Figure 18). In all cases except sand lance, there has been an increase in both the proportion of fish eaten, and the proportion of sand lance eaten. Indeed, the increase in fish consumption is due to an increase in sand lance consumption. This is also true of most of the other groups with an increase in trophic level, with the exception of haddock, pollock and transient mackerel, whose fish consumption increased, but not consumption of sand lance.

Table 65. Comparison of consumption (t·km^{-2}) in 1980-1985 and 1995-2000.

	1980-1985	1995-2000	20% Change	Significant?
1 Ceteaceans	2.33	2.66		
2 Grey Seals	0.30	1.68	↑	***
3 Seabirds	0.66	0.66		
4 Large Cod	2.56	0.14	↓	***
5 Small Cod	3.80	0.48	↓	***
6 Large Silver hake	5.92	1.81	↓	***
7 Small Silver Hake	16.57	12.93	↓	
8 Haddock	3.36	1.98	↓	
9 American plaice	1.29	0.72	↓	***
10 Large Halibut	0.08	0.04	↓	***
11 Small Halibut	0.04	0.28	↑	***
12 Flounders	1.76	1.80		
13 Skates	0.52	0.18	↓	
14 Dogfish	0.48	0.21	↓	
15 Redfish	6.80	2.80	↓	
16 Pollock	2.93	1.33	↓	
17 Transient Mackerel	1.30	0.47	↓	
18 Large Demersal Piscivores	0.60	0.14	↓	***
19 Small Demersal Piscivores	0.59	0.41	↓	
20 Large Demersal Feeders	0.24	0.09	↓	
21 Small Large Demersal Feeders	1.04	0.48	↓	
22 Small Demersal Feeders	1.11	3.33	↑	
23 Capelin	0.13	19.37	↑	***
24 Sand lance	8.46	45.58	↑	***
25 Transient Pelagics	0.09	0.09		
26 Small Pelagics	5.58	39.10	↑	***
27 Small mesopelagics	3.15	2.11	↓	
28 Squid	2.92	2.34		
29 Large Crabs	0.18	0.37	↑	
30 Small Crabs	2.53	5.67	↑	
31 Shrimp	31.26	153.36	↑	
32 Echinoderms	426.79	426.79		
33 Polychaetes	330.82	330.82		
34 Bivalve Molluscs	446.44	446.44		
35 Other Benthic Invertebrates	61.25	61.25		
36 Large Zooplankton	314.55	674.24	↑	
37 Small zooplankton	952.00	1232.00	↑	
Total	2640.44	3474.16	↑	

Table 66. Comparison of consumption (t·km^{-2}) of functional groups in 1980-1985 and 1995-2000.

	1980-1985	1995-2000	% change	Significant?
Cetaceans and birds	2.99	3.32	10.77	
Grey seals	0.30	1.68	468.00	***
Demersal Fish	49.69	29.15	-41.33	
Pelagic Fish	18.72	106.73	470.18	***
Commercial crustaceans	33.97	159.40	369.17	
Other invertebrates	1268.22	1267.65	-0.05	
Zooplankton	1266.55	1906.24	50.51	
Total	2640.44	3474.16	31.58	

The trophic level of small demersals increased because longhorn sculpin, whose diet consists of 66% fish (including sand lance), constitute a larger proportion of the biomass of this group in 1995-2000 than in 1980-1985. The trophic level of sand lance increased because significantly more large zooplankton are eaten in the 1995-2000 diet than in the 1980-1985 diet. It should be noted though, that only the 1995-2000 diet originates on the Scotian Shelf – the 1980-1985 diet was taken from Georges Bank (see above).

Many of the diets of the 1980-1985 model did not originate on the eastern Scotian Shelf, an unfortunate consequence of data availability and earlier research priorities. However, there is diet data available for silver hake and pollock for both time periods. These are compared directly in Table 67 and it is evident that for these species there has also been an increase in piscivory. The uncertainty analysis revealed that, even given the level of uncertainty in these diet estimates, many of the increase in fish are significant.

Table 67. Comparison of Silver hake and pollock diets, based on unaltered empirical diet data.

	Silver Hake		Pollock	
	1980-1985	1995-2000	1980-1985	1995-2000
Fish	0.36	0.72	0.30	0.41
Invertebrates	0.64	0.28	0.70	0.60
	1.00	1.00	1.00	1.00

Fishing Down the Foodweb

Fishing Down the Foodweb occurs when the average trophic level of the catch declines over time and the total catch decreases (Pauly et al. 1998, 2001). On the eastern Scotian Shelf, the average trophic level of the catch was relatively stable until the late 1980s. Since then, the trophic level of the catch has declined from an average of 3.6 to a low of 2.8 in 1999 (Figure 19). This is of concern since the total catch from the eastern Scotian Shelf has also declined (see above). A vacuum has been created at the higher trophic levels of the ecosystem, and now the fishery is steadily fishing down the foodweb.

These results hold whether only the trophic levels from the 1980-1985 model are used, or if the higher trophic levels from the 1995-2000 model are applied back to 1993.

Changes in Predator Structure

It has been shown that there has been a general increase in piscivory: the predator structure of the eastern Scotian Shelf has also changed considerably since 1980-1985 (Figure 20). During 1980-1985, cod was the main predator of fish and commercial invertebrates in the ecosystem. Other important predators included demersal piscivores (large and small) and silver hake. However, in 1995-2000, cod predation is minimal, whereas grey seals and silver hake (large and small) are the main predators of fish and commercial invertebrates. The biomass and consumption by grey seals has increased (see above) and they have become the main predator of fish. However, the biomass of, and consumption by large silver hake has decreased, yet it is an important predator of capelin and small pelagics, as well as pollock, haddock, small cod and silver hake. It was noted above that silver hake have become more piscivorous, which would explain this observation. Interestingly, small demersals also appear as top predators for sand lance and small crabs, due to the increase in the biomass of longhorn sculpin. Capelin and sand lance are important predators of shrimp.

Changes in Mortality

Mortality consists of 4 components, fishing mortality, predation mortality, loss (or gain) due to biomass accumulation and "other mortality". Other mortality can be thought of as deaths due disease, senescence, and environmental effects. However, it should also be considered as unexplained mortality, that is, the mortality that the model fails to account for. Figure 21 compares the distribution of this mortality across the fish groups in the two models.

Fishing Mortality

For the traditional commercial species such as cod, haddock and flounders there has been a reduction in fishing mortality from 1980-1985 to 1995-2000, as would be expected given the fisheries moratorium. Fishing mortality on other species such as halibut, small silver hake and demersal piscivores has increased. In recent years, a greater proportion of 1 year old silver hake have been caught (M. Showell, DFO, Pers. Comm).

Predation Mortality

Predation mortality has increased on species such as small cod, haddock, dogfish, redfish, pollock and demersal piscivores. These are all groups whose biomass has decreased from 1980-1985 to 1995-2000, and thus predation has a greater impact on these low biomass groups. In the case of small cod, haddock, redfish and demersal piscivores, total mortality is higher in 1995-2000 than 1980-1985.

In the case of haddock, total consumption of haddock and predation mortality increased from 1980-1985 to 1995-2000 due to the increased consumption of haddock by pollock and silver hake, despite decreased consumption by most other predators (Figure 22a). In 1980-1985, cod, haddock, pollock and grey seals were the main predators of haddock, whereas in the 1995-2000, pollock and silver hake are the dominant predators. Interestingly, these are two species for which there is empirical diet data from the eastern Scotian Shelf for both time periods. It is surprising though, that these predators would eat more haddock when haddock biomass is low, unless they were feeding on the very abundant 1998 and 1999 haddock year classes.

Predation mortality on small cod increased and accounts for 97 % of total mortality in 1995-2000. In the 1980-1985 model cod, demersal piscivores and grey seals were the main predators of small cod amongst a suite of other predators (Figure 22b). In 1995-2000, the main predators are similar, but also include silver hake, squid and cetaceans. The large increases in predation mortality observed are not due to increased consumption of small cod for consumption of small decreased from 35,000 tons to 13,200 per year, but to the large decrease in biomass of small cod. Thus the smaller amount of cod consumed has a larger impact on the smaller biomass of cod.

Predation mortality on large cod also increased, although it only constitutes 5 % of the total mortality in 1995-2000. The main predators in both time periods are grey seals, dogfish and demersal piscivores (Figure 22c). The increase in predation mortality is due to the grey seals, although consumption of cod by grey seals has decreased from 393-654 tons per year in 1980-1985 to 90-214 tons per year (ranges are from the analysis of uncertainty). Thus as with the small cod, large cod are very susceptible to predation due to their low biomass.

For other groups, predation mortality has decreased, for example, large and small silver hake, small halibut and the forage fish species. For the larger fish, such as silver hake whose biomass has decreased, the reduction in predation mortality is mapped by a decrease in consumption of large silver hake and is due to a decrease in predation by silver hake, dogfish and demersal piscivores, although predation by grey seals and transient pelagics increased. As shown in Figure 23a, there is a lot of uncertainty associated with these estimates, although the pattern holds.

In the case of the forage fish species (small demersals, sand lance, and small pelagics) small silver hake, shrimp and small crabs, the decrease in predation mortality is a consequence of the large increases in their biomass, and a decrease in the biomass of some of their predators (Table 63). Total consumption of each of these groups has increased greatly (except small crabs) in 1995-2000.

Consumption of sand lance increased from 123,410 tons per year in 1980-1985 to 509 351 in 1995-2000. Their main predators in 1980-1985 were cod, haddock, cetaceans and pollock, whereas in 1995-2000, their main predators are small demersals, small silver hake and grey seals (Figure 23b).

Shrimp have a wide range of predators, which consumed 456, 938 tons of shrimp per year in 1980-1985 and 2,239,239 tons of shrimp in 1995-2000. In 1980-1985, their main predators were redfish, small silver hake and small cod, whilst in the 1995-2000 they were small silver hake, sand lance and capelin, all of whose biomass is large in this time period (Figure 23c).

Other Mortality

There are substantial increases in the "other mortality" of several groups, the most notable being large cod, large and small silver hake, small halibut, small demersal piscivores, small demersals, capelin, sand lance and small pelagics (Figure 21). As noted above, "other mortality" can be considered mortality that is not explained by the model, and high "other mortality" generally indicates that total mortality is not well described in the model. This is fairly common in mass balance models, and should be used as a diagnostic to seek further understanding of the mortality term. The extent of this mortality is dependent on the input parameters P/B and biomass for the group in question, and the level of fishing and predation mortality experienced by each group (catch and diet and consumption of predators).

Some of the large unknown mortalities may be explained. For example, the large unknown mortalities of small pelagics and small demersals and to a lesser extent sand lance and capelin are due to their very large biomass and the reduced predator biomass. These are forage fish, whose abundance was low in 1980-1985 due to cropping by predators. All of these species increased during the 1990s since their predators have been largely removed by fishing, but no biomass accumulation term was used for these groups due to the large uncertainty associated with their biomass estimates. However, using the catchabilites for these two groups from the balanced model (see above), a BA rate of 0.16 yr^{-1} and 0.1 yr^{-1} was estimated for sand lance and small pelagics respectively. If these biomass accumulation terms are added to the model, the other mortality term is reduced, especially for sand lance (Table 68). Thus the production is much greater than the mortality, and $P/B \neq Z$. Note also that even with the large increase in grey seal abundance on the eastern Scotian Shelf, there is not enough consumption of these prey species to account for all their production.

Table 68. Comparison of mortality for sand lance and small pelagics without and with BA. All rates are yr^{-1}.

Model Type	Group	Z	F	M2	BA	MO
No BA	Sand lance	0.62	0	0.44	0	0.18
With BA	Sand lance	0.62	0	0.44	0.16	0.01
No BA	Small Pelagics	0.47	0.003	0.09	0	0.38
With BA	Small Pelagics	0.47	0.003	0.09	0.10	0.28

Large silver hake has a large "other mortality" estimate in both models, and small silver hake has a large "other mortality" term in the 1995-2000 model. The biomass estimates for both groups are quite uncertain, with a range of 81,000 to 191,000 tons in the 1980-1985 model. However, in the end, the lower end of the range of biomass estimates was used in both models for the large silver hake. The P/B estimates for these are among the highest for the fish groups. These are based on the premise that Z=P/B, and are based on estimates of Z. It is possible that Z has been greater than P/B for large silver hake since the 1980s because the biomass has decreased, but the biomass of small silver hake has remained relatively constant. A confounding factor with modelling silver hake is that the stock is not confined to the model area: it extends over the whole of the Scotian Shelf, and also into deeper waters off the shelf edge. It is thus possible that the model is failing to capture a mortality source that occurs outside the model area, or that the biomass or productivity occuring in the area has been misspecified.

Spiny dogfish have large "other mortality" terms in both models and this reflects a lack of knowledge of what may be preying on this species. The estimate of P/B was taken from the literature, and the estimate of biomass is quite uncertain. Thus this "other mortality" term may be real, or it may be an artefact of input uncertainty.

Perhaps the most concerning large "other mortality" term is the estimate for large cod. In the 1980-1985 model, this accounted for about 30 % of total mortality: in the 1995-2000 model, this increased to 88 %. Thus almost all the mortality of large cod is inexplicable in the 1995-2000 model. In the 1980-1985 model, the unaccounted mortality may be explained by inaccuracy in the actual amount of cod removed by harvesting (eg., unrecorded, under-recorded and mis-reported catches). However, in 1995-2000, since there is no fishery for cod this cannot be explained in this way. Furthermore, the actual total mortality, Z, estimated for large cod during 1995-2000 is higher than 0.5 yr^{-1} – it was estimated at 1.04 yr^{-1}. This was reduced in balancing the model, because such a high estimate created an impossibly large respiration/biomass ratio and P/Q (see above). Thus for large cod, the total estimated mortality is twice the production, so unless mortality is reduced, this population will continue to decline. On top of this, we do not know what is causing the mortality.

The question of high mortality estimates, particularly in large cod, is problematic and is common to many Canadian East Coast cod stocks, with the exception of NAFO Div. 4X cod. There have been DFO projects, workshops and papers written on this problem, but there is, as yet, no resolution (e.g. Chouinard et al. 2002, Powles 2002, Smedbol et al. 2002, Dutil et al. 2003). It remains at this stage to indicate that modelling the ecosystem with Ecopath has not been able to shed further light on this problem.

Ecosystem Statistics and Network Analysis

There are a range of aggregated ecosystem statistics that can be used to compare the eastern Scotian Shelf ecosystem in the 1980-1985 and 1995-2000. Essentially, these give an indication of the size of the system, and some indication of level of maturity. These are given in Table 69, together with the ranges produced by the uncertainty analysis.

The total system throughput is the overall size of the system and is the sum of consumption, exports, respiratory flows and flows to detritus. There is essentially no difference in the size of these systems as measured by total system throughput, or sum of all production. The uncertainty analysis confirms that the boundaries of the 95% confidence limits have a large overlap. There is also no difference in the total net primary production, total primary production/total biomass, total biomass/total throughput, total biomass or system omnivory.

The only differences between these systems at this aggregated level is the catch and the mean trophic level of the catch, which has significantly decreased between the two time periods.

Table 69. Comparison of System Statistics for 1980-1985 and 1995-2000 model

	1980-1985			1995-2000		
Parameter	Estimate	- 95% CL	+95% CL	Estimate	- 95% CL	+95% CL
Sum of all consumption	2640	1872	3434	3474	2214	4860
Sum of all exports	5.27	3.66	7.75	1.79	0.82	2.65
Sum of all respiratory flows	2776	1269	4335	2273	1423	3456
Sum of all flows into detritus	2247	687	3785	1375	647	2456
Total system throughput	7669	4481	10911	7124	5084	9975
Sum of all production	3241	1693	4853	2904	2025	4304
Mean trophic level of the catch	3.54	3.45	3.68	3.24	3.10	3.37
Gross efficiency (catch/net p.p.)	0.00062	0.00029	0.00103	0.00021	0.00012	0.00030
Calculated total net primary production	2776	1270	4336	2274	1423	3457
Total primary production/total respiration	1.00	1.00	1.00	1.00	1.00	1.00
Net system production	0.35	-0.94	2.78	0.62	-0.19	1.15
Total primary production/total biomass	11.34	5.59	17.53	7.34	4.97	10.68
Total biomass/total throughput	0.032	0.021	0.045	0.043	0.034	0.050
Total biomass (excluding detritus)	245	176	312	310	228	397
Total catches	1.73			0.49		
Connectance Index	0.38			0.39		
System Omnivory Index	0.15	0.13	0.18	0.14	0.12	0.16

Network Analysis

There are several network analysis statistics that can be compared between the two systems.

Cycling: Cycling has been positively related to maturity and stability (Odum 1969, Christensen and Pauly (1993) and to recovery time (Vasconcellos et al., 1997), although this may not be as straightforward as Odum first envisaged (Christensen et al. 2000). Cycling is quantified in ECOPATH using the Finn Cycling Index (FCI, Finn 1976), which is defined as the fraction of an ecosystem's throughput that is recycled. In Ecopath, it is expressed as a percentage of the total flows. Another index related to the recovery time of an ecosystem is mean path length (Vasconcellos et al., 1997). The mean path length is the average number of groups that a unit of flow passes through on its way from inflow to outflow (Christensen 1995b). Path length will be affected by diversity of flows and cycling. Since these increase with increasing maturity, it is assumed that long path lengths are associated with mature ecosystem

The results for the 1995-2000 model indicate that there is more cycling, with a greater mean path length in the 1995-2000 ecosystem than in 1980-1985 (Table 70). However, when uncertainty is incorporated into this analysis, the ranges for the estimates for the two periods have large overlaps, indicating that, given the uncertainty, they cannot be distinguished.

Ascendancy: Ascendancy is a derived product and is essentially a measure of the potential for growth and development of an ecosystem and its potential for competitive advantage over other network configurations (Ulanowicz, 1986). It is a measure of the average mutual information in a system, scaled by the system throughput, and is derived from information theory. The upper limit that ascendancy can reach is called the development capacity, and the difference between the capacity and the ascendency is called 'system overhead'. The overheads provide limits on how much the ascendency can increase and reflect the system's 'strength in reserve' from which it can draw to meet unexpected perturbations (Ulanowicz 1986). Thus, a system with high ascendency will have high development, and generally will be very diversified, while a system with high overhead will be resilient and have strength in reserve (Heymans et al. 2002).

The ecosystem in both time periods has a large overhead, suggesting that they should be resilient ecosystems, and this is indicated by the high measure of resilience in Table 70. However, there is essentially no difference between the two time periods for any of the measures in Table 70.

Table 70. Estimates from Network Analysis from the 1980-1985 and 1995-2000 Ecopath models.

	1980-1985			1995-2000		
	Estimate	- 95% CL	+95% CL	Estimate	- 95% CL	+95% CL
Cycling						
Finn's cycling index (% of total throughput)	4.89	1.88	8.38	6.61	3.62	8.90
Finn's mean path length	2.76	2.32	3.26	3.13	2.69	3.54
Predatory cycling index (% of throughput w/o detritus)	0.22	0.03	0.45	0.33	0.11	0.63
Ascendancy						
Ascendency (Flowbits)	6786	4829	9525	7578	5680	10323
Overhead (Flowbits)	24433	15579	31018	24654	16030	33274
Capacity (Flowbits)	31219	20835	40116	32232	22463	42843
Information	0.88	0.73	1.16	1.06	0.85	1.29
Resilience=O/C	78.26	71.99	80.77	76.49	70.09	80.58
A:C	21.74	19.23	28.01	23.51	19.42	29.91
H=C/T	4.07	3.44	4.56	4.52	3.90	4.79

From a fish centric view, it was anticipated that there would be some impact of the collapse of groundfish and increase in invertebrates, forage fish and grey seals at the ecosystem level. However, these results indicate that these changes have no detectable effect on either the aggregated ecosystem indices or the network characterstics of the ecosystem. The energy flow to and from these groups is small compared to the total energy flow in the system. For example, total consumption by sand lance in 1995-2000 is 46 $t{\cdot}km^{-2}$, whereas the sum of all consumption is 3474 $t{\cdot}km^{-2}$ (Table 69). Most consumption occurs at trophic level 2 (Figure 24), so in effect changes at higher trophic levels are unlikely to have an impact on ecosystem indices that are dominated by lower trophic levels.

UNCERTAINTIES IN THE DATA

Comparison of biomass estimates from Ecopath and independent surveys

In the course of balancing the two models, some of the biomass estimates that were originally inputs to the model were subsequently estimated by the model. The model estimated biomass is compared to the original biomass estimates (Figure 25). In the 1980-1985 model, the main differences are the large increase in biomass of sand lance, small demersals, squid and shrimp and smaller increases in the biomass of transient pelagics and large zooplankton. The biomass of large and small silver hake and redfish decreased. In all cases the independent biomass estimates to which these are compared have a high level of unknown uncertainty. The 95 % confidence limits estimated from the uncertainty analysis for large and small silver hake, sand lance squid and shrimp do not include the independent estimate (although there are no confidence limits associated with these estimates). In the 1995-2000 model, the picture was similar, except that the increase in shrimp, squid and large zooplankton biomass was greater, the small pelagics and sand lance decreased by 50 % and small zooplankton biomass increased. In this case, the 95 % confidence limits estimated from the uncertainty analysis for large silver hake, redfish, small demersal feeders, sand lance, small pelagics, squid, shrimp and large zooplankton do not include the independent estimate (again there are no confidence limits associated with these estimates).

The change in biomass between the two model periods for these groups as estimated from the independent surveys and by Ecopath were compared to see if they were consistent (Table 71). For many of these groups, the relative change in biomass between the model periods is consistent. However, there is a very large difference for sand lance, and there are large differences for the small pelagics and shrimp. These are discussed further below.

Table 71. Comparison of Ecopath biomass with Independent estimates of biomass

Groups in italics were estimated by the model. Groups underlined were dependent on either the 1980-1985 or the 1995-2000 Ecopath estimate of biomass.

	80-85	95-00	Change	Independent estimate
Large Silver hake	0.799	0.329	0.41	0.41
Small Silver Hake	*2.132*	2.230	1.05	1.15
Redfish	3.400	1.400	0.41	0.44
Small Demersal Piscivores	*0.113*	0.078	0.69	0.90
Large Demersal Feeders	*0.104*	0.047	0.45	0.49
Small Large Demersal Feeders	*0.223*	0.120	0.54	0.64
Small Demersal Feeders	*0.260*	0.780	3.00	3.66
Sand lance	*1.104*	11.200	10.15	212.67
Transient Pelagics	0.046	*0.046*	1.00	?
Small Pelagics	*1.215*	8.500	6.99	14.83
Squid	*0.656*	*0.526*	0.80	0.57
Small Crabs	*1.687*	3.780	2.24	increase ?
Shrimp	*2.767*	*13.571*	4.91	1.97
Large Zooplankton	*16.131*	*34.576*	2.14	?
Small zooplankton	34.000	44.000	1.29	decrease ?

Sand lance

In the case of sand lance, the estimates of biomass from the RV survey are poor, and catchability adjusted estimates uncertain. In Table 32, a range of biomass estimates, based on different assumptions about catchability was reviewed. It had been assumed that catchability was the same in both time periods. If the ratio of RV biomass in the 1995-2000 to 1980-1985 is maintained, then there is either insufficient biomass in the 1980-1985 model to meet demand, or the biomass estimate in the 1995-2000 is unrealistically high. Thus in balancing the two models, it became apparent that the 200-fold difference in sand lance biomass between the two time periods estimated from the RV survey was not feasible. Instead, it was assumed that catchability must have changed between the two time periods, and that as sand lance density increased, they became more catchable. The 1980-1985 model estimate of biomass implies a catchability of around 0.0005. Biomass in the 1995-2000 model was reduced to half of the original estimate, implying a catchability of 0.01. Thus catchability is estimated to have increased 20 times.

Small Pelagics

A similar argument can be made for the small pelagics. Catchability was assumed to be 0.025 for both time periods. The estimate for the 1980-1985 was adjusted upwards by 5 % in balancing the model, a negligible difference given the uncertainty associated with these estimates. The 1995-2000 estimate was reduced by 50 %, implying a catchability of 0.05, and a change in catchability of 100 %.

Shrimp

The Ecopath model estimated the biomass of shrimp in both time periods. The difference between these estimates and those based on shrimp trawl surveys are large (Figure 25, Tables 70, 71). The estimates from the shrimp trawl surveys are for *Pandalus borealis* only, and these were adjusted upwards by 25% to account for other shrimp species (see Table 43). The shrimp biomass estimates from the trawl surveys increased by 100 % over the two time periods while the Ecopath estimated shrimp biomass increased by 500 %.

There is uncertainty associated with both the shrimp trawl estimates of biomass and the Ecopath estimates of biomass. The shrimp trawl only estimates the biomass of *P. borealis,* whose catchability to the trawl may be less than 1. In addition the biomass of the many other shrimp species is not estimated by the shrimp trawl survey, and is thus unknown.

The Ecopath estimate of biomass is derived from the consumption of shrimp by their predators. The main predators of shrimp (80 % of total consumption of shrimp) in the 1980-1985 model are redfish, small silver hake, small cod, small pelagics and large cod, and in the 1995-2000 model are small silver hake, sand lance and capelin. With the exception of large cod in the 1980-1985 model, these are all groups for which there is high uncertainty associated with their biomass estimates. This uncertainty is transferred to uncertainty in the biomass estimates of shrimp.

There is thus a large degree of uncertainty associated with the estimates of shrimp biomass (Table 72), indicating that if this uncertainty were resolved, the Ecopath estimates of biomass could be closer to the shrimp trawl estimates.

Table 72. Comparison between Ecopath and Shrimp trawl estimates of biomass for 1980-1985 and 1995-2000. 95 % confidence intervals are given for the Ecopath estimates of biomass.

	1980-1985	1995-2000	Difference
Shrimp trawl biomass estimate (t·km^{-2})	0.102	0.201	1.97
Ecopath biomass estimates (t·km^{-2})	2.77 (± 2.19)	13.57 (± 12.04)	4.90
Difference	27.13	67.52	

Large zooplankton

Abundance or biomass estimates of large zooplankton are poor. The CPR data is not considered a reliable indicator of euphausiid biomass because of their large size relative to the opening of the sampling net. The CPR data do indicate lower abundance in the 1990s than in the 1970s, but the trend from the 1980s to the 1990s is unknown. There are thus no data with which to compare the model estimates of biomass, or the biomass change between the two time periods.

Small zooplankton

In the absence of other information, the same biomass estimate was used as input for both 1980-1985 and 1995-2000 model, even though the estimate was derived from late 90s data. However, given that the 1995-2000 model required a greater biomass of small zooplankton than the 1980-1985 model, small zooplankton biomass is modelled here to increase by 29 %. CPR data shows a decreased from the 1960s and early 1970s to the 1990s, but again, the trend between these two time periods is unknown.

Other Uncertainties

In addition to the uncertainties outlined above, one important area that has not been discussed is the unknown mortality due to discarding of fish in commercial fishing operations. Discards can include small fish of the target species, target species when the fishing vessel is over quota and non-commercial species. The extent of mortality due discarding on the eastern Scotian Shelf cannot be estimated since there are no estimates of discards available. Research to explore the extent of discarding from both interview surveys of fishermen and analysis of observer and log book data (Halliday 1998) was unsuccessful. It was concluded that discarding could not be reliably estimated from comparison of the observer to shore and log book data (P. Fanning, FAO, Pers. Comm.). The absence of discard estimates could have a large influence on the model results.

There is large uncertainty concerning the input estimates for the lower trophic levels such as the benthos groups, especially their biomass estimates. Essentially, the dynamics of the lower trophic levels are not modelled well due to lack of information. Very approximate estimates of biomass were used as input values to these models, and in each only 10 – 45 % of the production was used within the model. The question arises as to what happens to the rest and since the bacterial loop is not modelled, this question cannot begin to be answered. Note too that most of the trophic flow occurs at these trophic levels (Figure 24) and thus we know least about the part of the ecosystem the is its the bedrock. Better data and modelling at this level would help understand the bentho-pelagic coupling on the eastern Scotian Shelf.

There is essentially uncertainty associated with all the data inputs used in these models. In order to understand the effects of uncertainty on model estimates, a simple uncertainty analysis consisting of 30 duplicates was conducted (biomass and diet were perturbed with inputs selected randomly a range set using the pedigree routine of Ecopath - see above for more details). Where appropriate the results of the uncertainty analysis have been discussed throughout the results section. In general, they have been used to determine where differences between the two time periods are real.

A simpler analysis of uncertainty is to conduct a sensitivity analysis using a routine within Ecopath for this purpose. Here, the biomass, P/B and Q/B are changed by plus or minus 50 % in 10 % increments and the effect on model estimates of the missing parameter shown.

Sensitivity Analysis

In both models, a very few groups exert a large influence on the parameter estimates of other groups (Figure 26). In the 1980-1985, these groups are small silver hake (sensitive groups are large zooplankton, small zooplankton and small mesopelagics), small demersal piscivores (sensitive groups are large crabs and flounders), small mesopelagics (squid) and large zooplankton (small zooplankton). In each case, a -50 % change in the input parameter produced a 40 % or greater change in the estimated parameter for each of the groups in brackets. In the 1995-2000 model, large zooplankton again exerted a strong influence on the small zooplankton, and small mesopelagics on squid. However, squid (small demersal piscivores) and transient pelagics (dogfish) were the only other groups to which other groups were hyper sensitive. Small silver hake was still influential in the 1995-2000 model, but less so (Figure 9).

All the groups had a high degree of sensitivity to their own input parameters (with the exception of the cetaceans whose missing parameter, EE, is zero). In the 1980-1985 model, the most sensitive groups are small silver hake, large zooplankton and small mesopelagics. 1995-2000 model, the most sensitive groups are large zooplankton and small mesopelagics. It has been noted that the biomass estimated for small silver hake are not well estimated, even with q-correction. Given the sensitivity of other groups to small silver hake in the 1980-1985 model, and its auto-sensitivity, it is important to be able to describe this group better.

DISCUSSION AND CONCLUSIONS

At the whole ecosystem level, there has been little change in the eastern Scotian Shelf ecosystem from the 1980-1985 to the 1995-2000, despite the collapse of the groundfish and increase in invertebrates and forage fish. However, at a less aggregated level, there have been substantial changes in the ecosystems. Even allowing for uncertainty in the model estimates, some clear conclusions can be drawn from the analysis presented here.

There has been a considerable shift in the pelagic to demersal ratio, caused by both an overall reduction in the biomass of demersal fish and a very large increase in the biomass of pelagic fish, notably sand lance and small pelagics. Overall biomass has increased, but consumption has increased more, indicating a greater proportion of small species with high a consumption rate. The trophic level of many groups has in increased, and this is due to both an increase in piscivory and an increase in the trophic level of one of the main prey items, sand lance. The increase in piscivory makes sense, given the great abundance of forage fish.

Although there is greater piscivory in the ecosystem, the predator structure has changed. In the 1980-1985, cod was the main predator, whereas in the 1995-2000, grey seals and silver hake are the main predators. Total consumption by grey seals, silver hake and cod is less in 1995-2000 than it is in 1980-1985. There is thus less consumption by top predators in 1995-2000.

There are large unknown mortality estimates for several groups. The ecosystem has greatly changed and there are few top predators in1995-2000. Unknown mortality may be due to disease or senescence because there is not sufficient predation. However, for species whose biomass is decreasing such as large cod or large silver hake, this cannot be the explanation. Even allowing for uncertainty, the unknown mortality is large. There maybe unknown mortality that is not specified in the model, the input data for the group, eg, P/B and biomass estimates may be wrong, or both.

There are several concerns with these models, but perhaps the most important are the large estimated biomass of shrimp and the increase in the biomass of both zooplankton groups between the two model periods. This is not supported by the trends in the Continuous Plankton Recorder data. The sensitivity analysis indicated that the greatest sensitivity in the model was small zooplankton to large zooplankton. Unfortunately this is where data is poor.

An analysis of the effects of uncertainty of the input data on model estimates was performed, for perhaps the first time, in the comparison of two Ecopath mass balance models. This was a very informative exercise. For example, the 95 % confidence limits for the estimates of sand lance biomass in the 1980-1985 model were 21,935 t. and 195,325 t. This is almost a two fold range. In many cases, the uncertainty associated with the model estimates was sufficiently wide to disable conclusion about differences between the two models. This was especially the case with the aggregated indices such as the network analyses. Where difference exist, there can be confidence that these differences are real. This type of analysis should be carried out routinely with Ecopath models. Unfortunately there is no easy way to do this, and currently, only the biomass and diet can be perturbed with a predefined range of uncertainty. The ranges of uncertainty (in the pedigree routine) are predefined and the base model value is always in the centre of the distribution. Greater flexibility in the autobalance routine would further enable this type of analysis.

RESEARCH RECOMMENDATIONS

Building an Ecopath mass balance model is a little like puzzling over a jigsaw – all the pieces of the puzzle must fit together in order to create the whole picture. Unlike a jigsaw puzzle, the final picture is not foreknown, nor is it certain once completed. However, the process of putting the puzzle together is very informative: the pieces that do not fit well are clearly identified, and indeed there are tools such as the sensitivity analysis to help identify the problem pieces. In this way, Ecopath is a book-keeping or accounting exercise. It helps to evaluate the input data and how well it fits the "big picture" when put together. This provides recommendations for where it is critical to gain further information, to clarify model uncertainty and to provide a more robust picture of the ecosystem.

In the case of the eastern Scotian Shelf model, there are a few key areas where better data would resolve uncertainty. These areas include zooplankton biomass, benthic biomass, sand lance and silver hake biomass. Biomass scales the system and currently the biomass of these groups is not estimated well (see above). There is currently great interest in ecosystem issues and ecosystem based management within DFO (Jamieson and O'Boyle 2001, Oceans Act 1997, Arbour 2002), yet many of the basic building blocks for developing a better understanding of the ecosystem are simply not available: they are either not systematically sampled, or they are not sampled well.

Zooplankton has been sampled through time and there is a DFO regional database for this data (Biochem). However, the data are derived from various surveys with different aims and different gear. Since 1999, data have been collected under the auspices of the Atlantic Zone Monitoring Program, but this is from one station only (Station 2). This data will in time provide information on zooplankton abundance trends for that area, but not biomass or abundance estimates for the eastern or western Scotian Shelf. A systematic sampling scheme over the Scotian Shelf, providing data on both large and small zooplankton, is required.

The benthos has been sparsely and sporadically sampled (Stewart et al. 2001): again, a systematic sampling scheme across the Scotian Shelf is required. Sampling could use old technologies such as grabs and sledges, but also new methods of viewing the benthos such as side scanners and underwater photography.

The catchability of fish to the RV trawl survey was estimated from Shelton et al (2001). Their analysis should be considered a first step that requires both further refinement and ground-truthing. Catchability adjusted biomass estimates of silver hake, redfish, sand lance and herring were too high, and had to be reduced in the model. In order to verify empirically the biomass of highly abundant species such as sandlance and herring, a dedicated forage fish survey is required. One such project has been undertaken, as a beginning to this process. DFO Science and the Groundfish Enterprise Allocation Council (GEAC) have completed a 2 year Joint Project Agreement to invesigate, amongst other objectives, the relative abundance indices for forage species and other commercial species. The results of this combined trawl and accoustic survey are being worked up (P. Fanning and W. Maceachern, DFO, Pers. Comm)

For the first time since the 1960s, CDEENA conducted a multispecies, systematic stomach survey on the Scotian Shelf (1999-2002), and a diet database has been developed. In order for ecosystem research, including research on ecosystem structure and function, predator/prey relationships and natural mortality to continue, stomach surveys and diet analysis must be continued. Currently, they are not.

Mass balance modelling with Ecopath and Ecosim is only one approach to gaining a wider and greater understanding of ecosystem changes and their impact on structure and function, foodweb relations, predator/prey relationship or natural mortality. The research presented here for the eastern Scotian Shelf should be considered simply as the results from one modelling exercise, which may give insight to the structure and function of the ecosystem and the changes that have occurred.

The original thinking behind the CDEENA project was to include at least two modelling approaches, Ecopath and some sort of dynamic minimum realistic model. Two mass balance approaches were used, Ecopath and Inverse Modelling and compared (Savenkoff et al 2001) but unfortunately there were insufficient resources to accommodate an alternative modelling approach. However, one very positive offshoot of CDEENA is the concurrent creation of three permanent research scientist positions in Quebec, Newfoundland and Maritimes. There are established working relationships between these individuals and plans afoot for further ecosystem and multispecies modelling.

Given the efforts behind CDEENA, the commitment to ecosystem research and the commonalities among the east Coast marine ecosystems, it behooves DFO to sustain the working relationships that have been established during the life time of CDEENA and the ecosystem modelling work that has been undertaken. This could be acheived through the establishment of a Zonal Committee on ecosystem research. Modelling the east coast ecosystems with mass balance models should be considered as the first step in a much larger exercise. Indeed, mass balance modelling with Ecopath and Ecosim is only one approach to gaining a wider and greater understanding of ecosystem changes and their impact on structure and function, foodweb relations, predator/prey relationship or natural mortality.

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Further research includes the use of other modelling approaches that start from different premises, such as Global models (Yodzis 1998), multispecies VPA, models with more focus on the lower trophic levels, alternative food web models and minimum realistic models. Alternative modelling approaches would provide support (or not) for conclusions made here, and may offer alternative views of the ecosystem and of any change that may have occurred. In addition, models can be constructed at different scales, e.g, larger, for the whole Scotian Shelf, or smaller, and for areas not yet complete, eg., the western Scotian Shelf.

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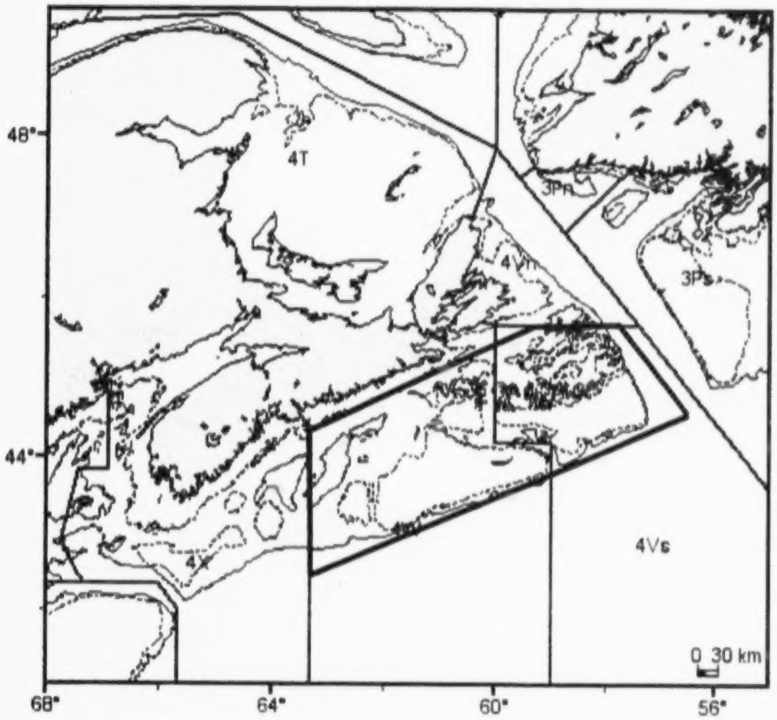
48°
44°
4T
3Pn
4Vn
3Ps
4Vs
4X
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68°
64°
60°
56°

Figure 1. Map of the Scotian Shelf, showing the eastern Scotian Shelf model area.

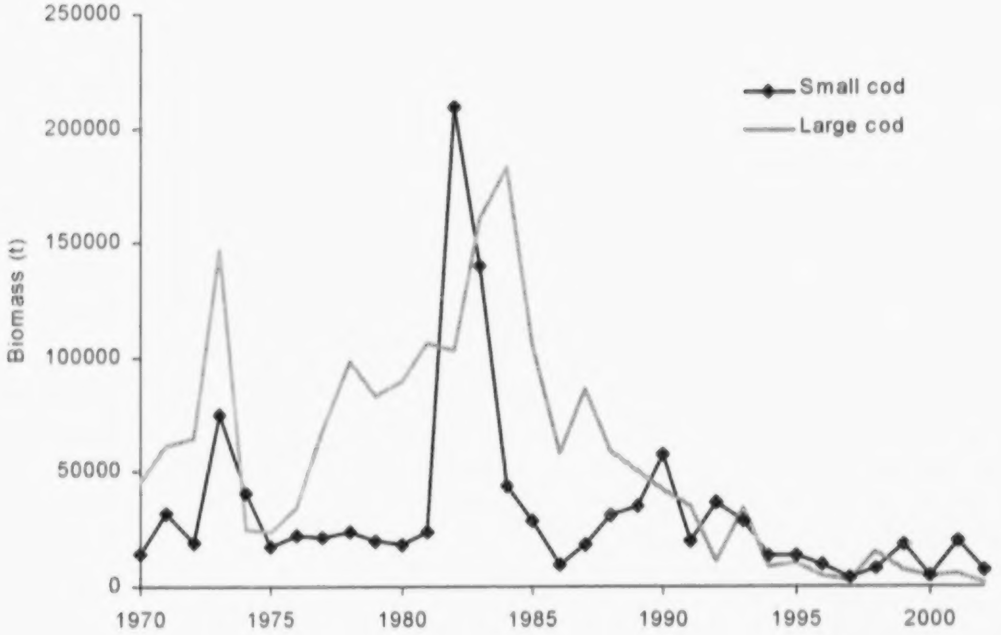


Figure 2. q-adjusted RV estimates of large and small cod biomass, 1970-2002

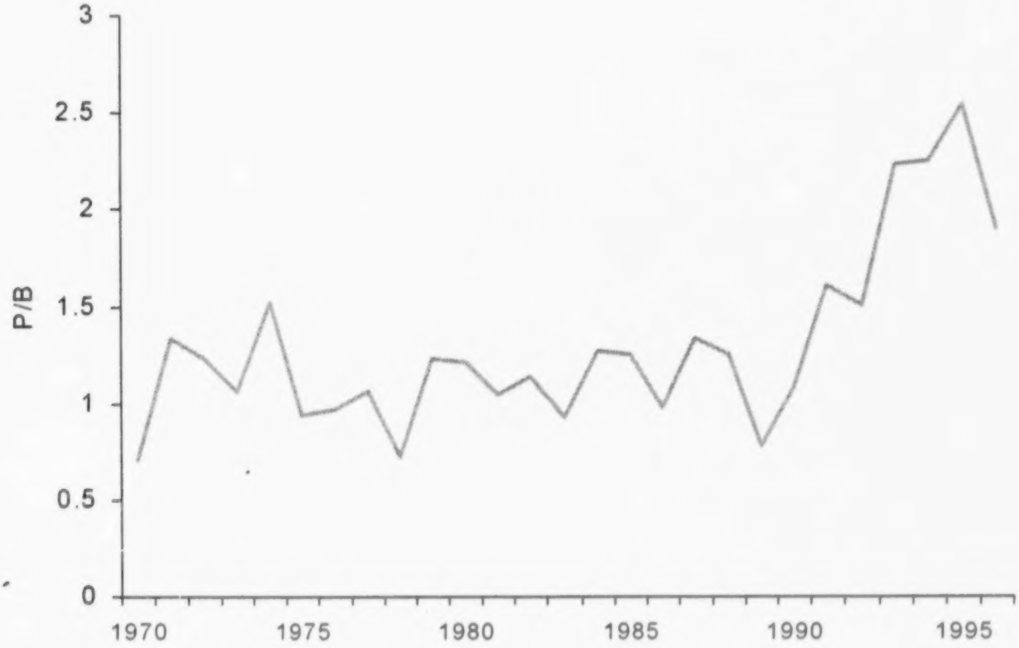


Figure 3. P/B ratio of small cod, estimated from sequential population analysis

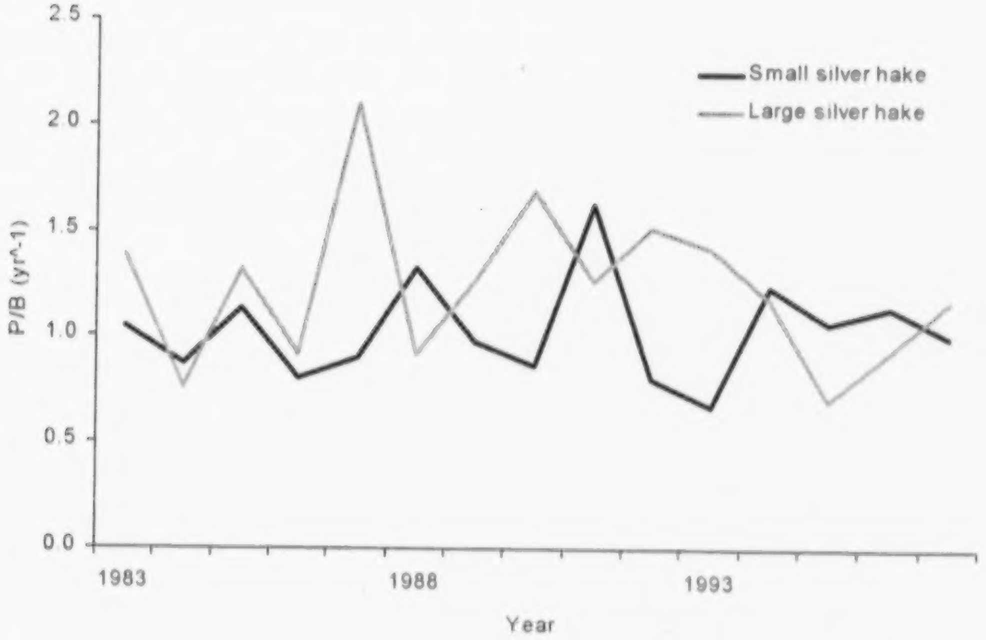


Figure 4. P/B ratio of large and small silver hake, estimated from sequential population analysis.

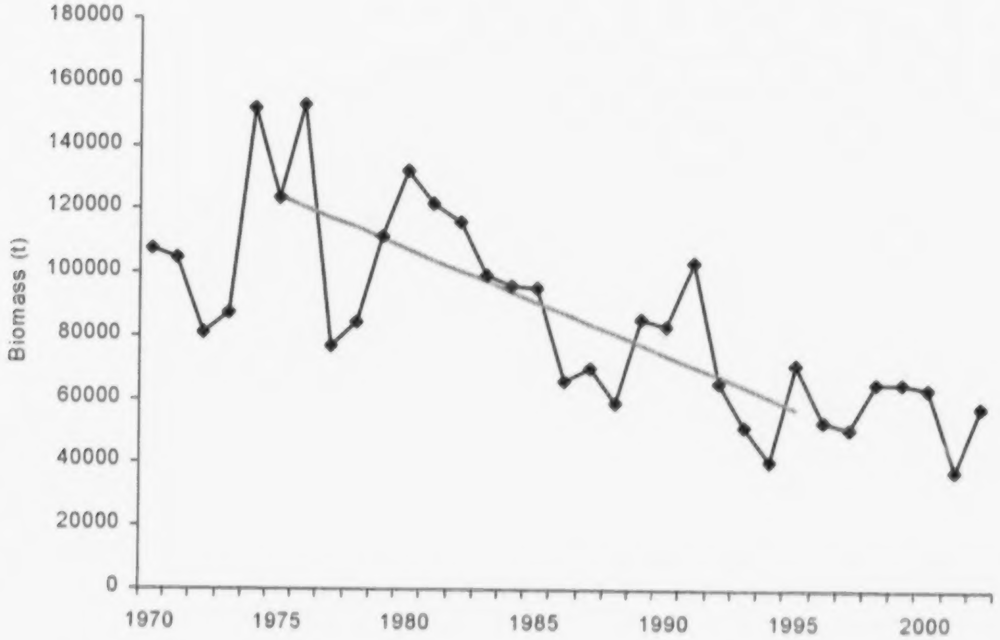


Figure 5. Catchability adjusted biomass of American plaice, showing regression used to estimate biomass accumulation

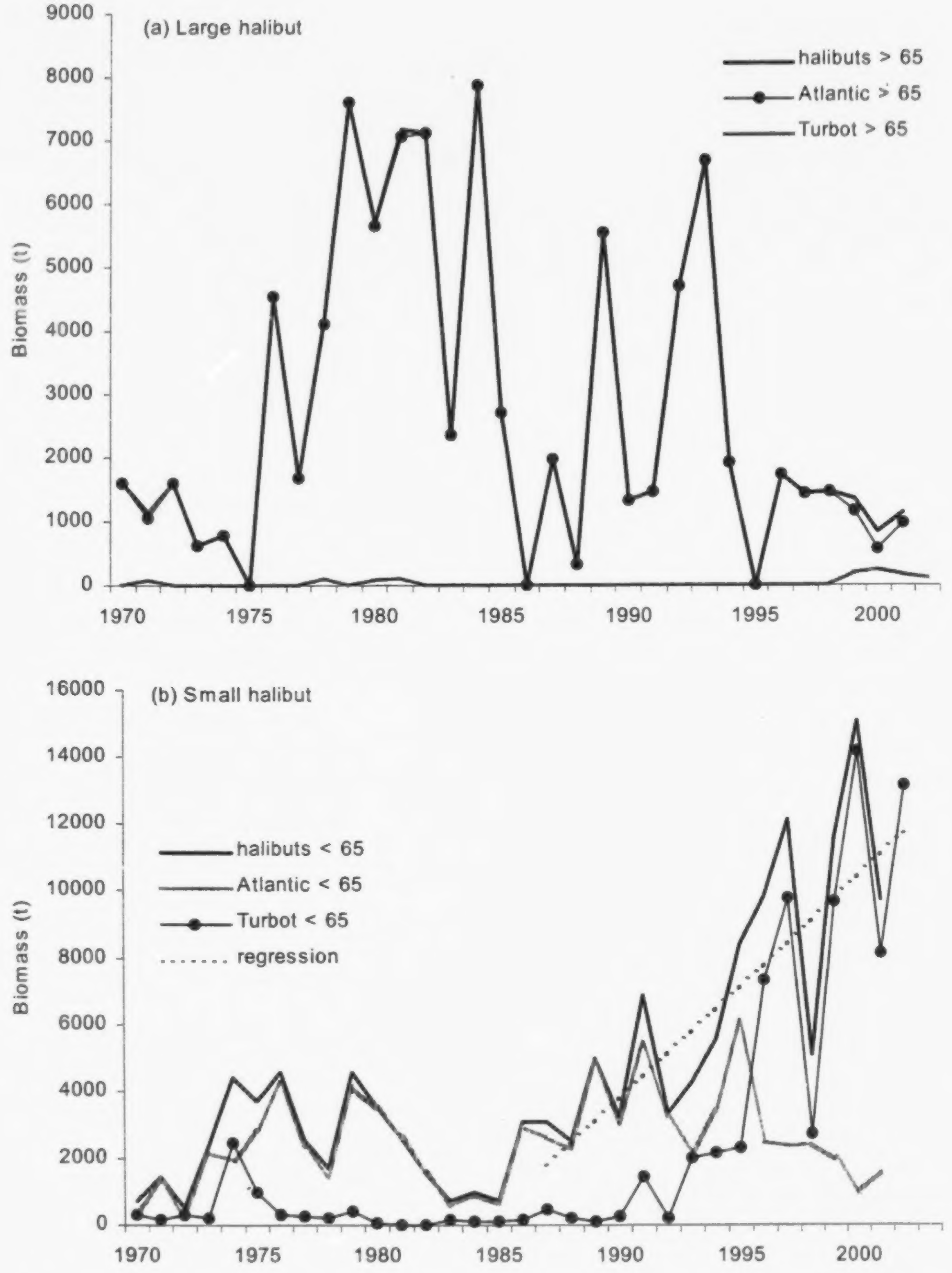


Figure 6. Biomass (t) of (a) large and (b) small halibut on the eastern Scotian Shelf. The regression used to estimate biomass accumulation of small halibuts is shown in (b).

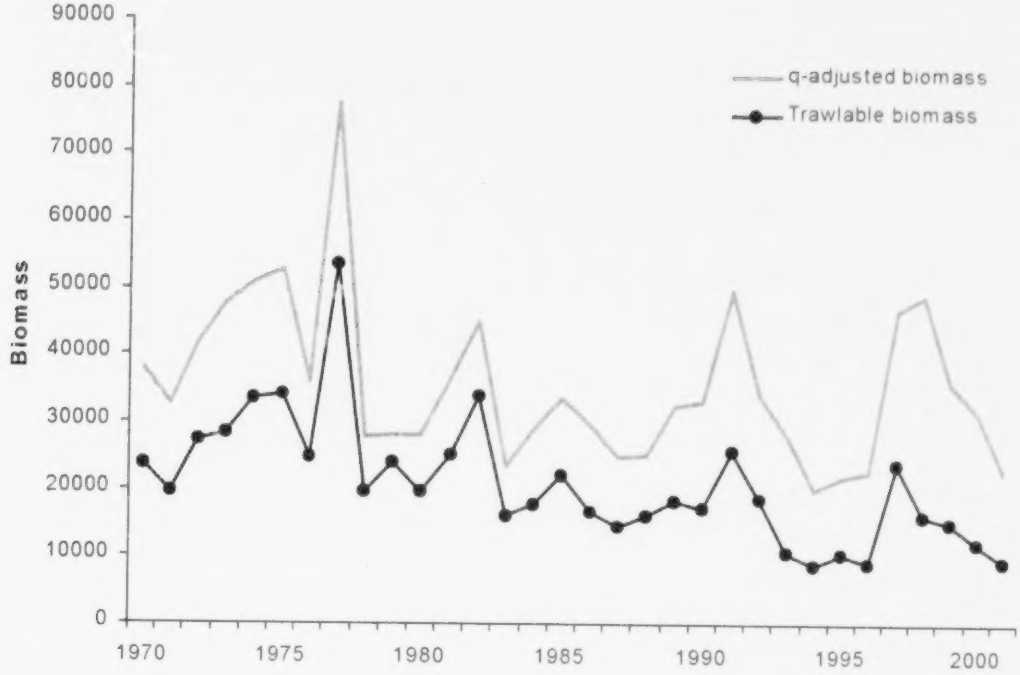


Figure 7. Trawlable and q-adjusted estimated of skate biomass from RV Survey data

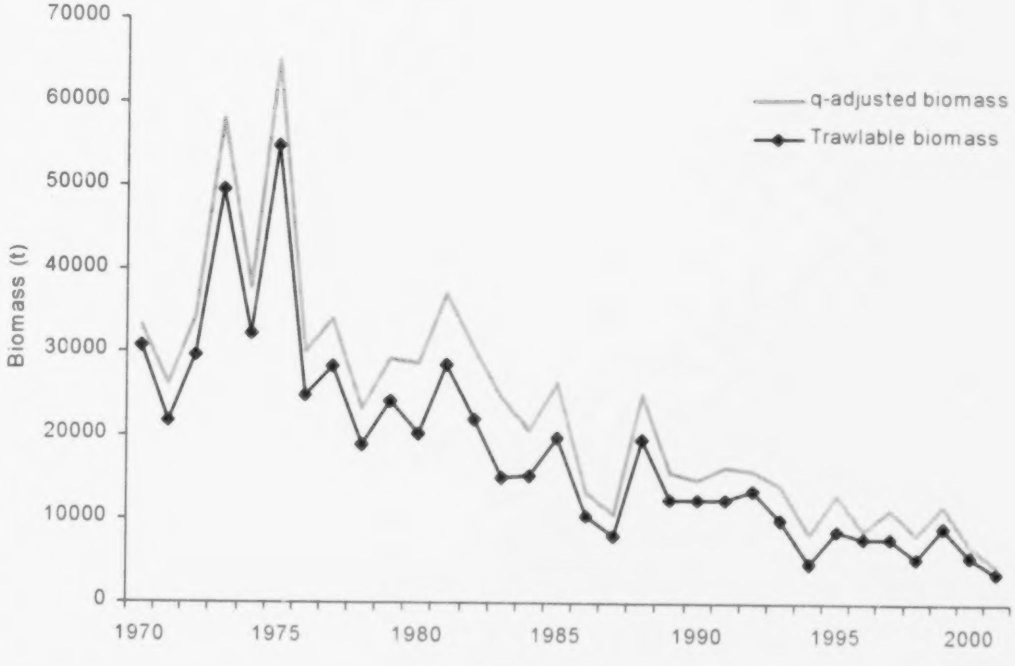


Figure 8. Trawlable and q-adjusted estimated of skate biomass from RV Survey data

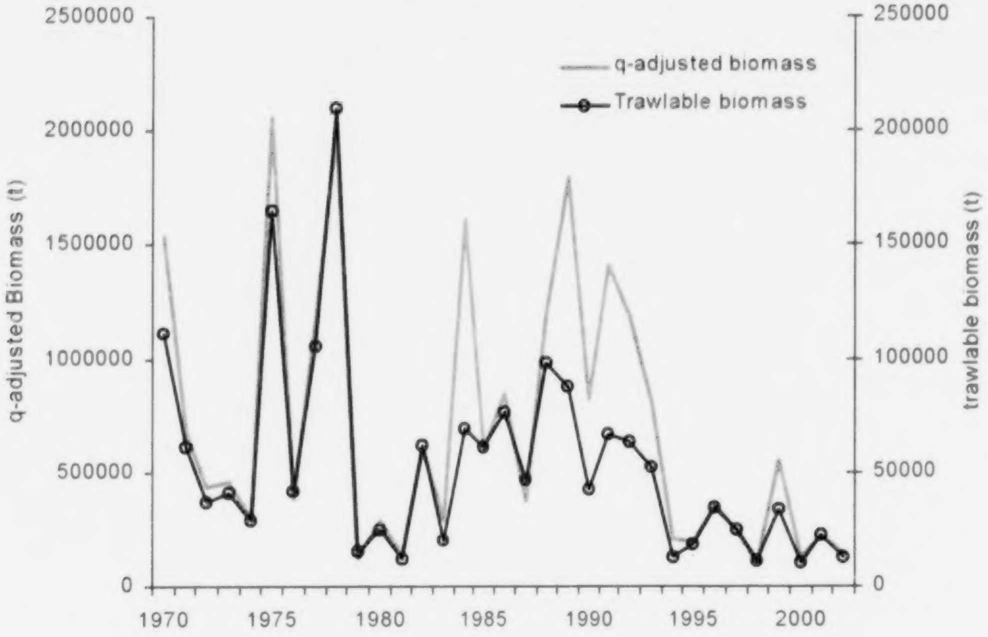


Figure 9. Trawlable and q-adjusted estimated of redfish biomass from RV Survey data

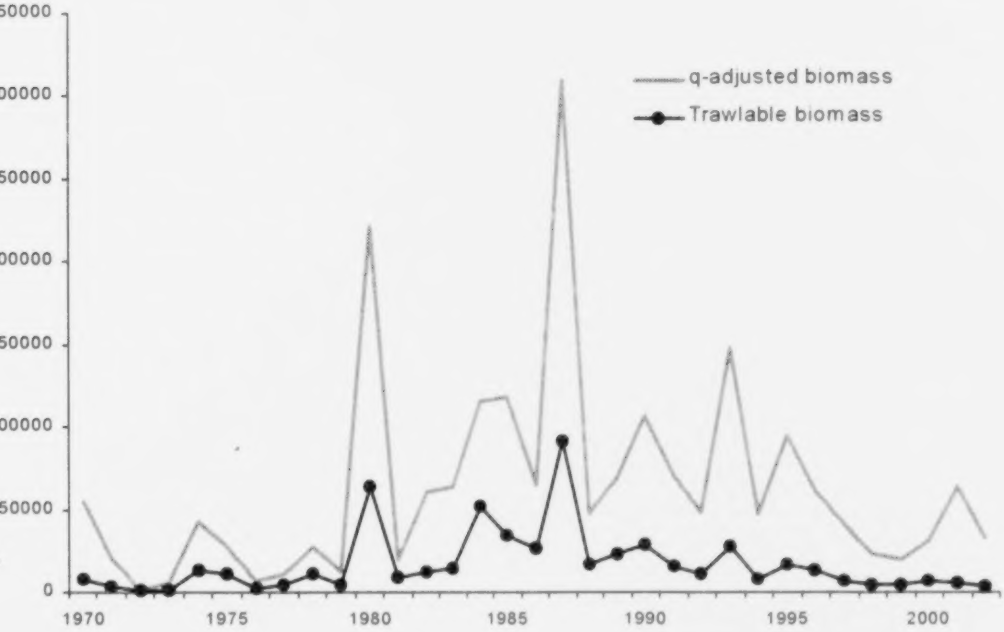
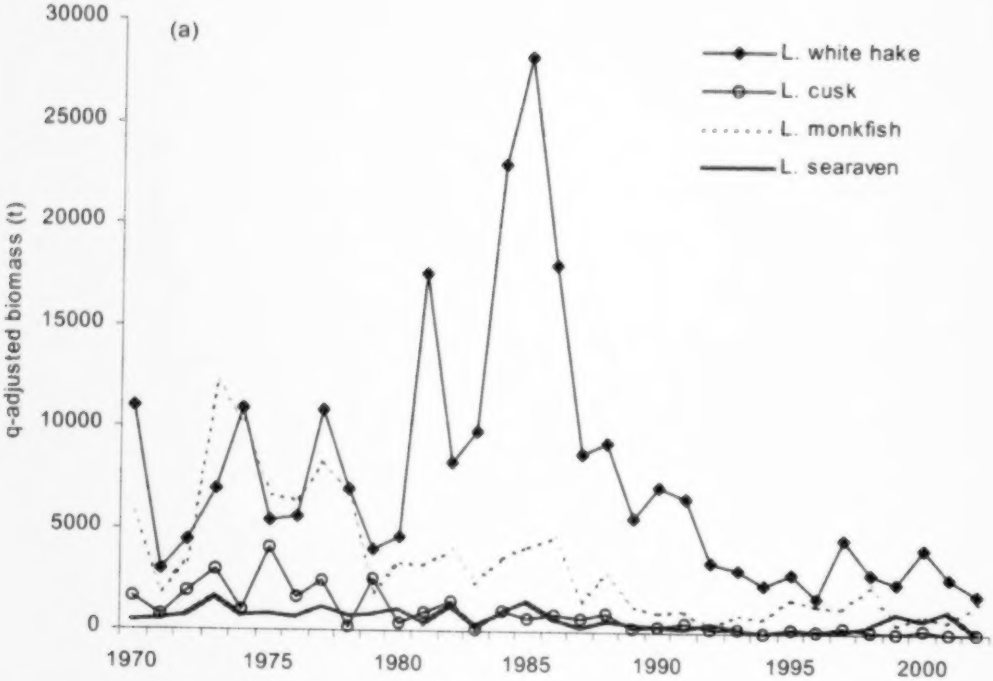


Figure 10. Trawlable and q-adjusted estimated of pollock biomass from RV Survey data



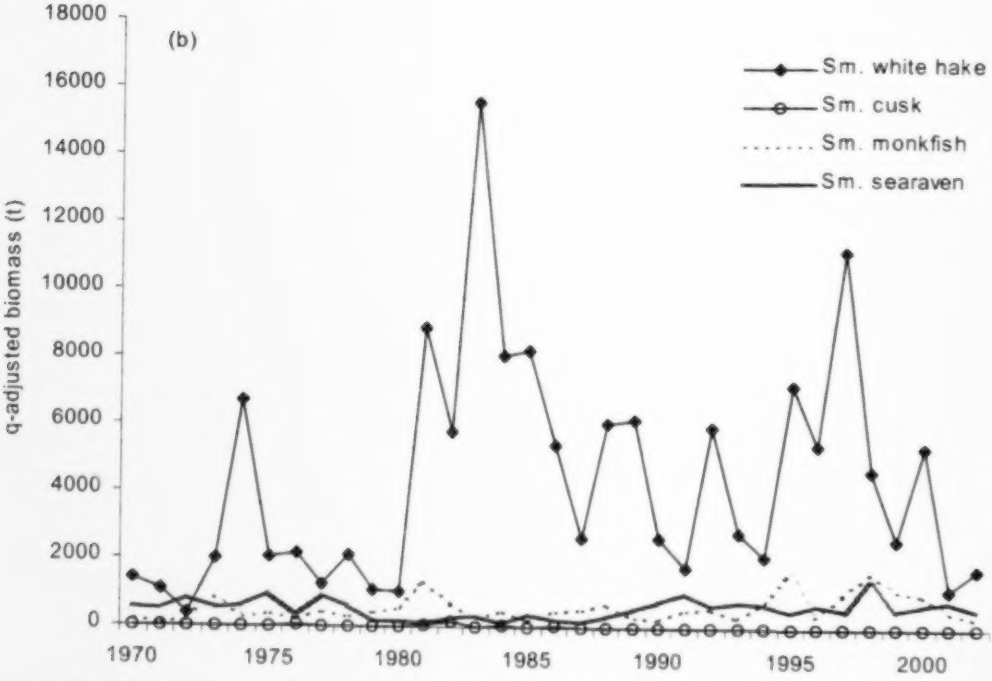
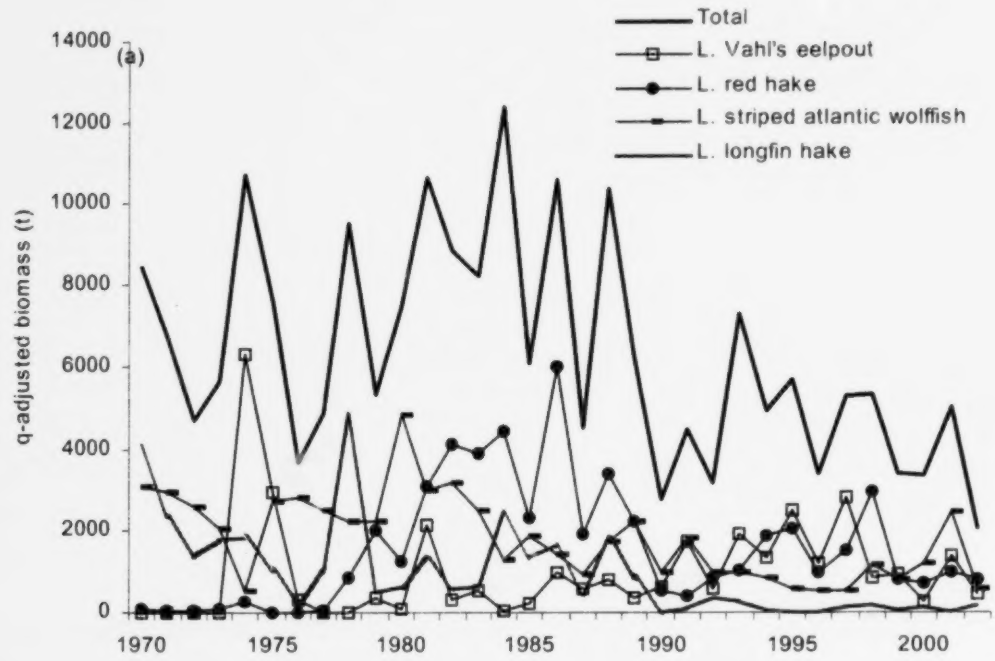


Figure 11. . q-adjusted estimated of(a) large demersal piscivore biomass and (b) small large piscivore biomass



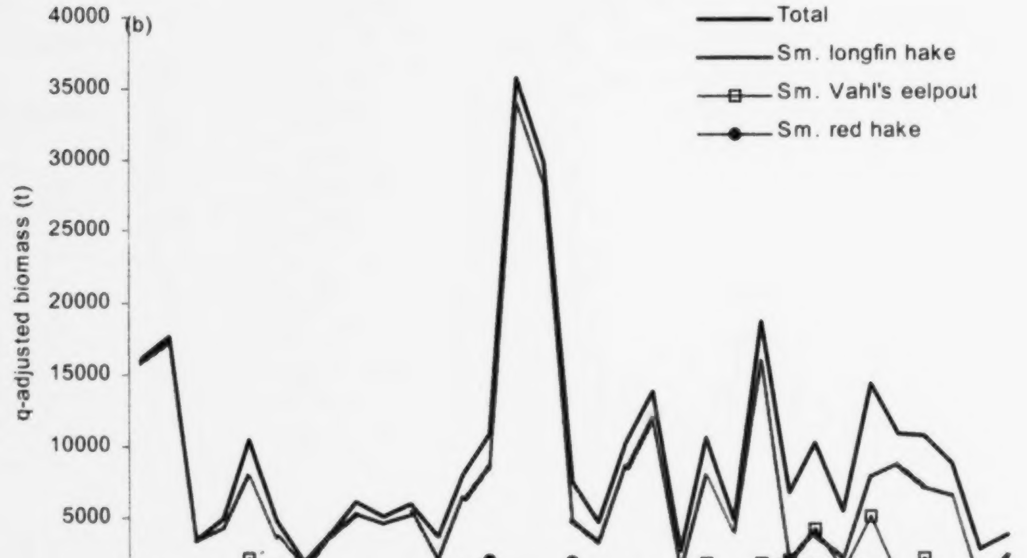


Figure 12. q-adjusted estimated of(a) large demersal feeder biomass and (b) small large demersal feeder biomass

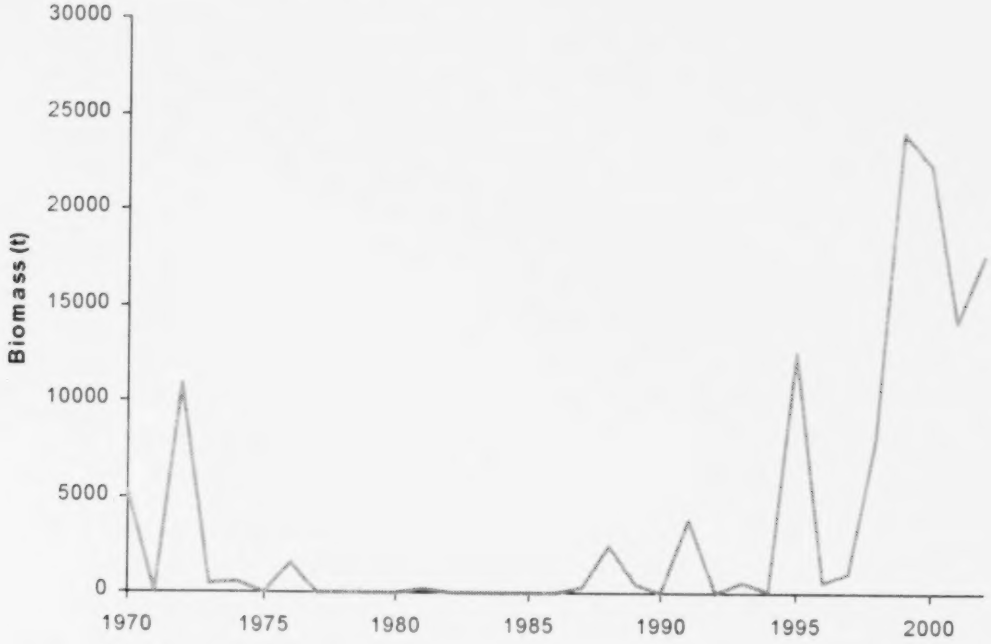


Figure 13. Research vessel estimates of trawlable biomass of sand lance

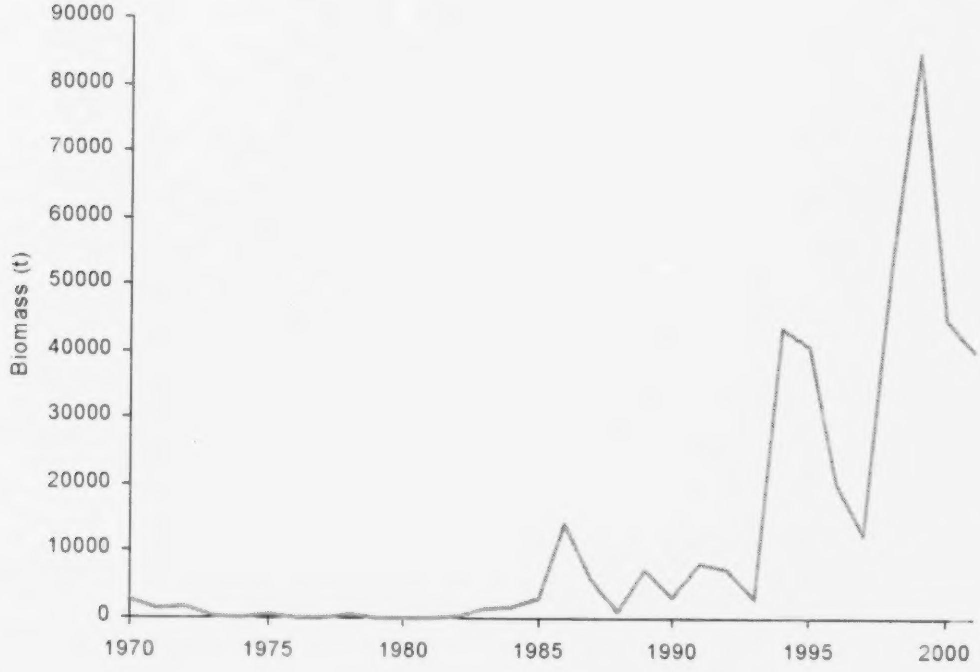


Figure 14. Research vessel estimates of trawlable biomass of herring.

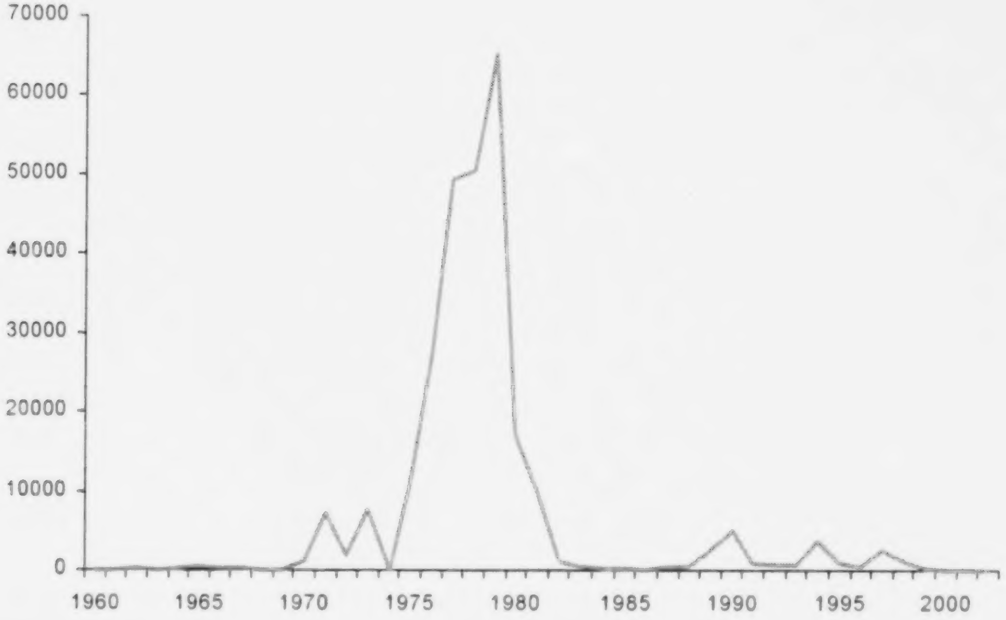


Figure 15. Catch of short-finned squid (t) from the eastern Scotian Shelf, 1960-2002.

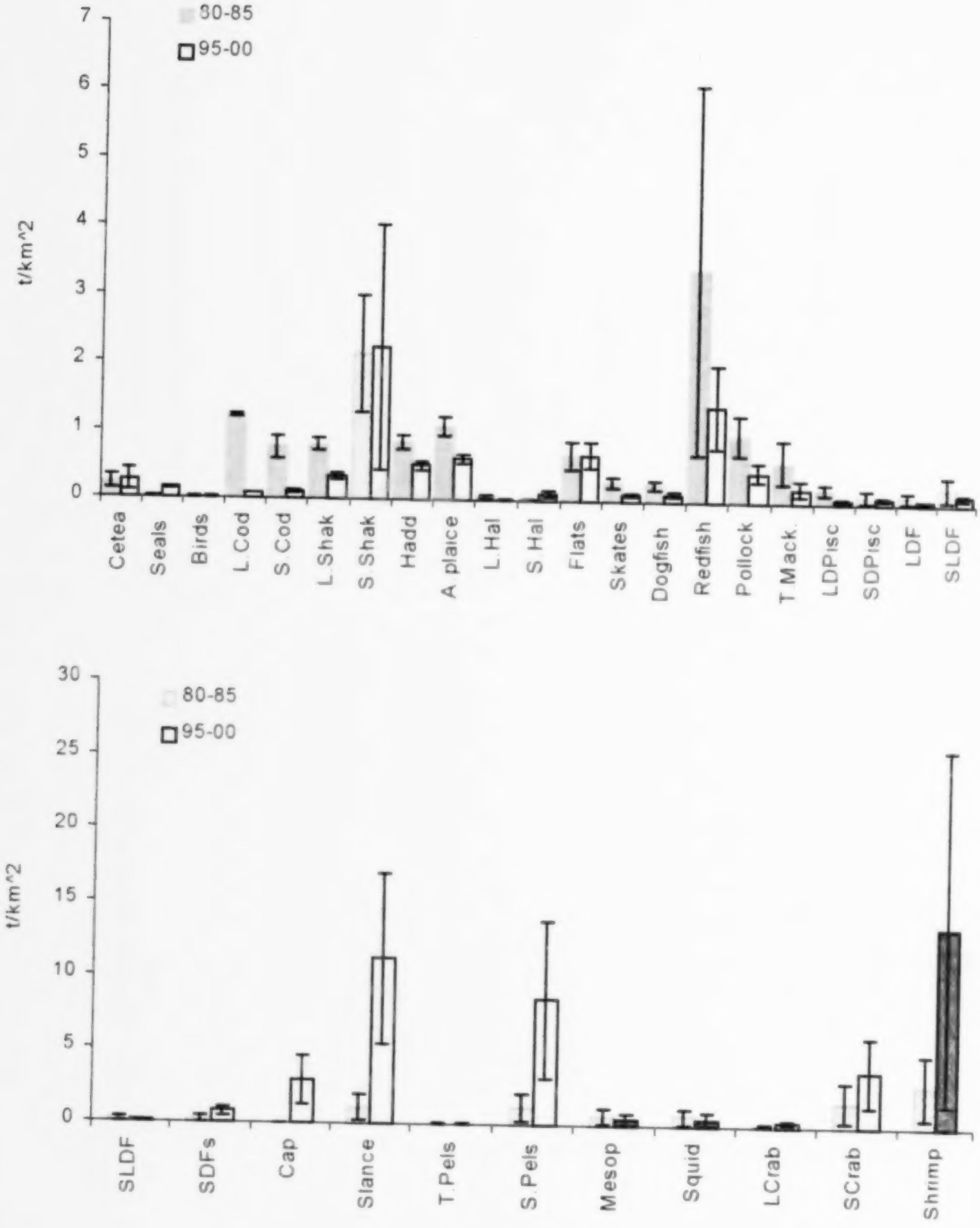


Figure 16. Biomass inputs and estimates from the 1980-1985 and 1995-2000 models. Model estimates are striped. Error bars are from the uncertainty analysis.

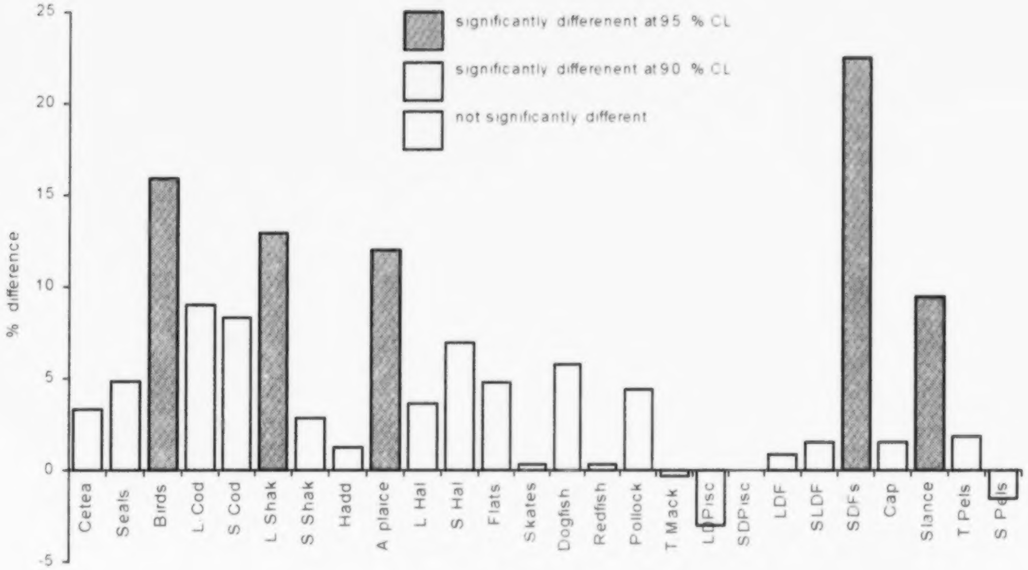


Figure 17. Percent change in trophic level from 1980-1985 to 1995-2000. Significance levels are derived from the uncertainty analysis - see text for further details.

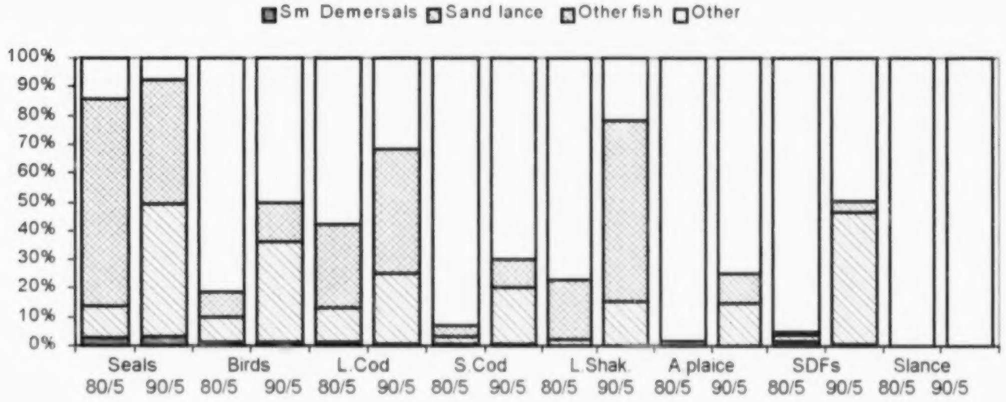


Figure 18. Percentage of small demersal, sand lance, other fish and other prey in the diet of groups with significantly increased trophic levels in the 1980-1985 and 1995-2000 balanced models. Shaded areas represent total percentage of fish.

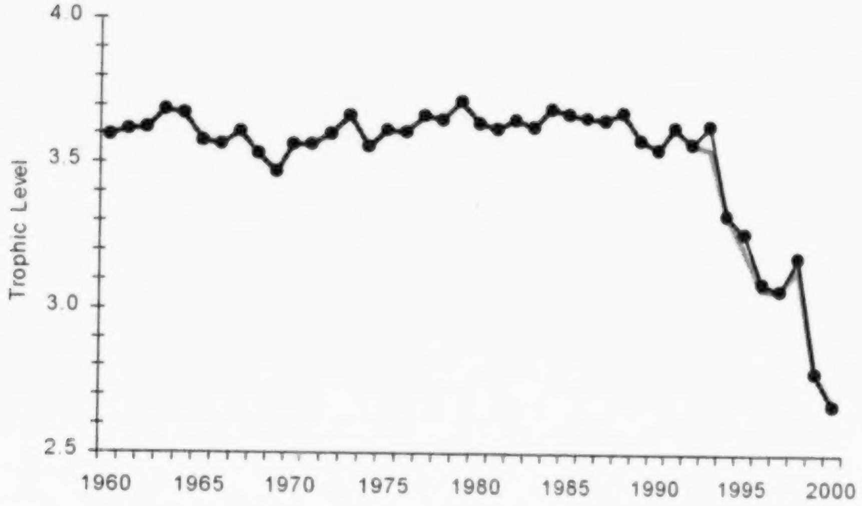
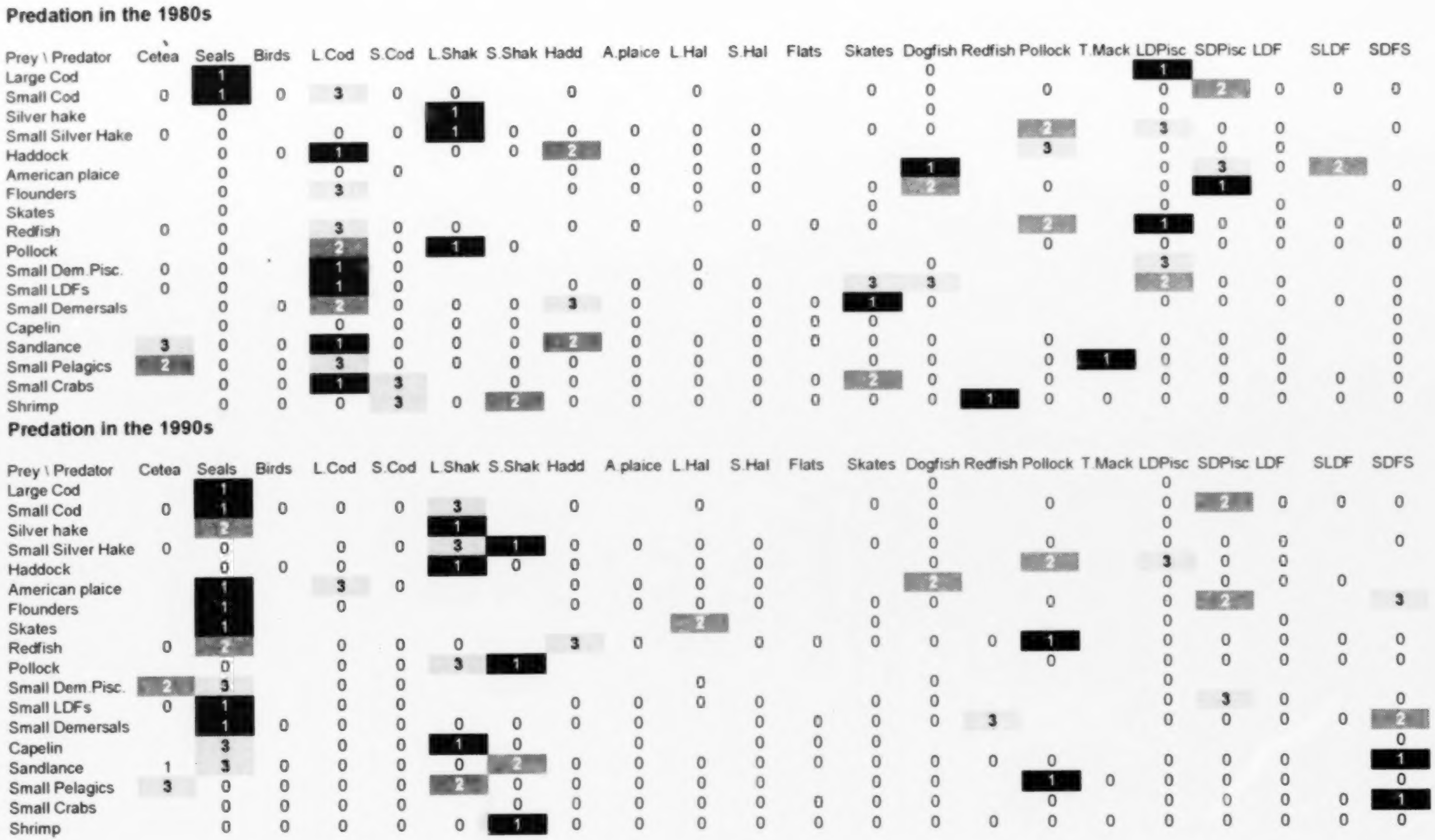


Figure 19. Average trophic level of the catch. Trophic level is based on 1980-1985 trophic level (thick line) and 1980-1985 (1960-1992) and 1995-2000 trophic levels (1993-2000). Trophic levels are derived from Ecopath models.



Predation in the 1980s

Prey \ Predator	Cetea	Seals	Birds	L.Cod	S.Cod	L.Shak	S.Shak	Hadd	A.plaice	L.Hal	S.Hal	Flats	Skates	Dogfish	Redfish	Pollock	T.Mack	LDPisc	SDPisc	LDF	SLDF	SDFS
Large Cod		1												0				1				
Small Cod	0	1	0	3	0	0		0		0			0	0		0		0	2	0	0	0
Silver hake		0				1								0				0				
Small Silver Hake	0	0		0	0	1	0	0	0	0	0		0	0		2		3	0	0		0
Haddock		0	0	1		0	0	2		0	0					3		0	0	0		
American plaice		0		0	0			0	0	0	0			1				0	3	0	2	
Flounders		0		3				0	0	0	0		0	2		0		0	1			0
Skates		0								0			0					0		0		
Redfish	0	0		3	0	0		0	0		0	0	0			2		1	0	0	0	0
Pollock		0		2	0	1	0									0		0	0	0	0	0
Small Dem.Pisc.	0	0		1	0					0				0				3				
Small LDFs	0	0		1	0			0	0	0	0		3	3				2	0	0		0
Small Demersals		0	0	2	0	0	0	3	0		0	0	1	0				0	0	0	0	0
Capelin		0		0	0	0	0		0		0	0	0									0
Sandlance	3	0	0	1	0	0	0	2	0	0	0	0	0	0		0		0	0	0		0
Small Pelagics	2	0	0	3	0	0	0	0	0	0	0		0	0		0	1	0	0	0		0
Small Crabs		0	0	1	3		0	0	0	0	0	0	2	0		0		0	0	0	0	0
Shrimp		0	0	0	3	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Predation in the 1990s

Prey \ Predator	Cetea	Seals	Birds	L.Cod	S.Cod	L.Shak	S.Shak	Hadd	A.plaice	L.Hal	S.Hal	Flats	Skates	Dogfish	Redfish	Pollock	T.Mack	LDPisc	SDPisc	LDF	SLDF	SDFS
Large Cod		1												0				0				
Small Cod	0	1	0	0	0	3		0		0			0	0		0		0	2	0	0	0
Silver hake		2				1								0				0				
Small Silver Hake	0	0		0	0	3	1	0	0	0	0		0	0		0		0	0	0		0
Haddock		0	0	0		1	0	0		0	0			0		2		3	0	0		
American plaice		1		3	0			0	0	0	0			2				0	0	0	0	
Flounders		1		0				0	0	0	0		0	0		0		0	2			3
Skates		1								2			0					0		0		
Redfish	0	2		0	0	0		3	0		0	0	0	0	0	1		0	0	0	0	0
Pollock		0		0	0	3	1									0		0	0	0	0	0
Small Dem.Pisc.	2	3		0	0					0				0				0				
Small LDFs	0	1		0	0			0	0	0	0		0	0				0	3	0		0
Small Demersals		1	0	0	0	0	0	0	0		0	0	0	0	3			0	0	0	0	2
Capelin		3		0	0	1	0		0		0	0	0									0
Sandlance	1	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0		0	0	0		1
Small Pelagics	3	0	0	0	0	2	0	0	0	0	0		0	0		1	0	0	0	0		0
Small Crabs		0	0	0	0		0	0	0	0	0	0	0	0		0		0	0	0	0	1
Shrimp		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 20. Comparison of predature structure in the 1980-1985 and 1995-2000 Ecopath models. For each prey in the left hand column, the top 3 predators are marked in the rows. Other predators are indicated by a zero.

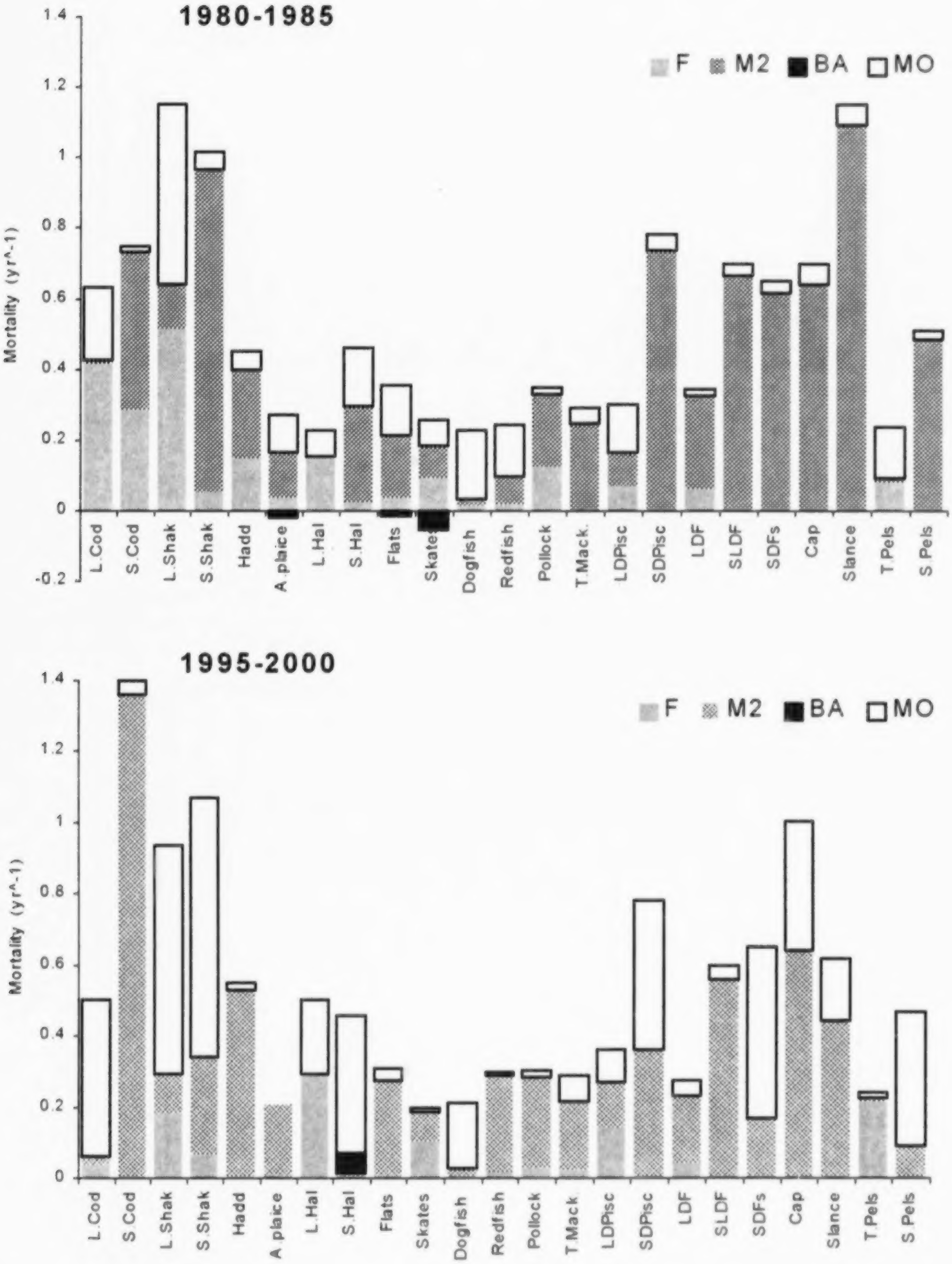


Figure 21. Distribution of mortality over fish species in 1980-1985 and 1995-2000 models

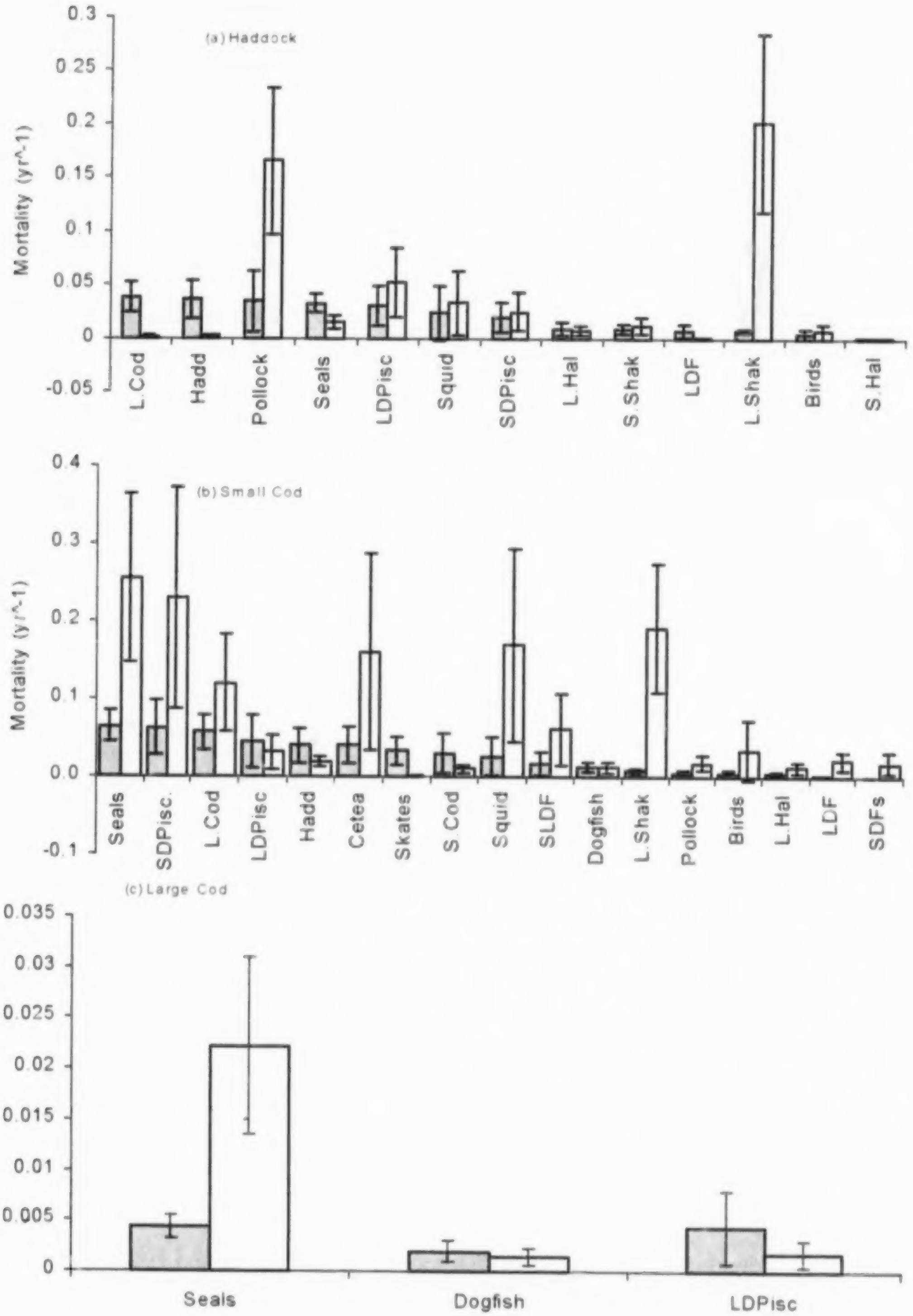


Figure 22. Predation Mortality on (a) Haddock, (b) Small cod and (c) Large cod

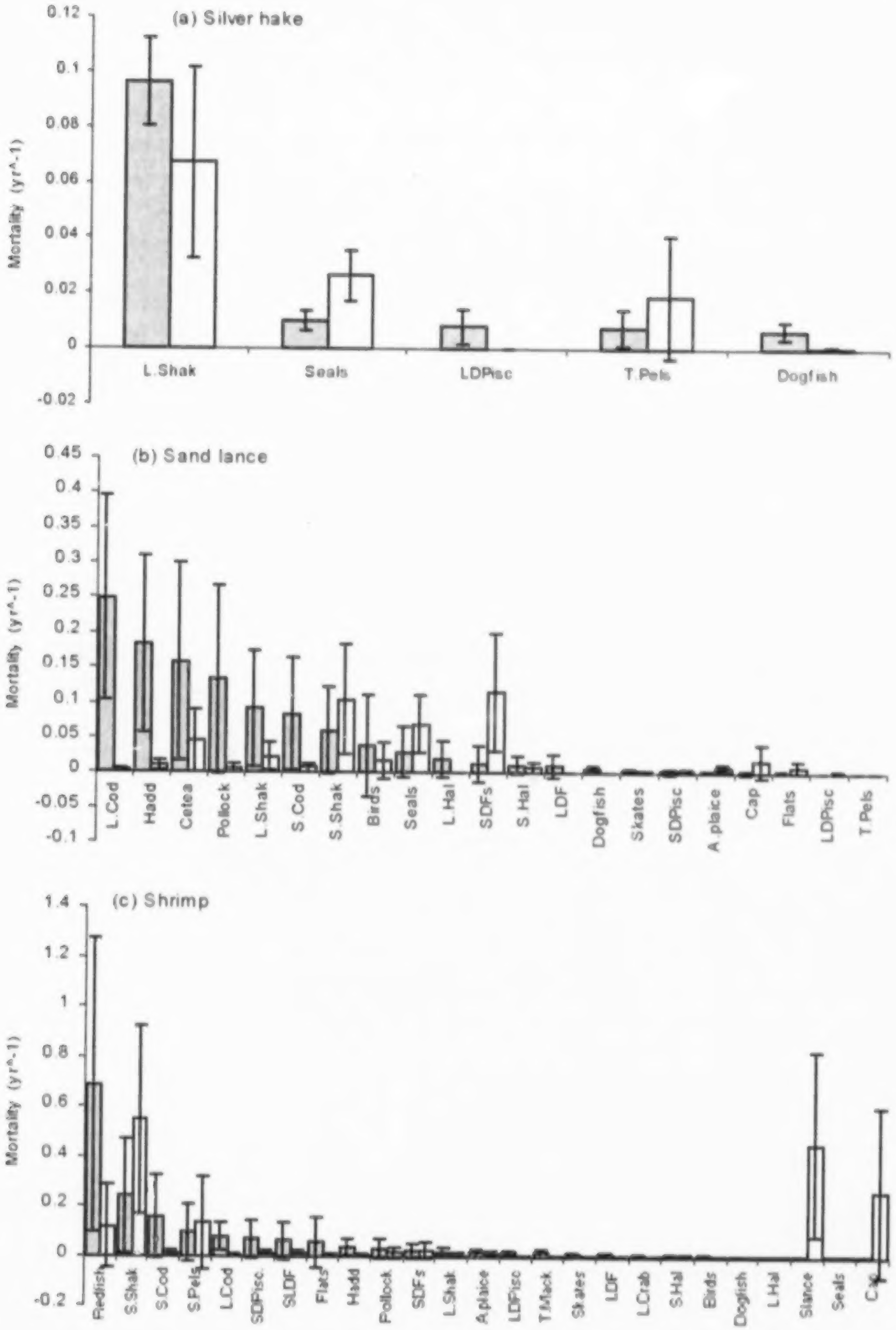


Figure 23. Predation Mortality on (a) Silver hake (b) Sand lance and (c) Shrimp

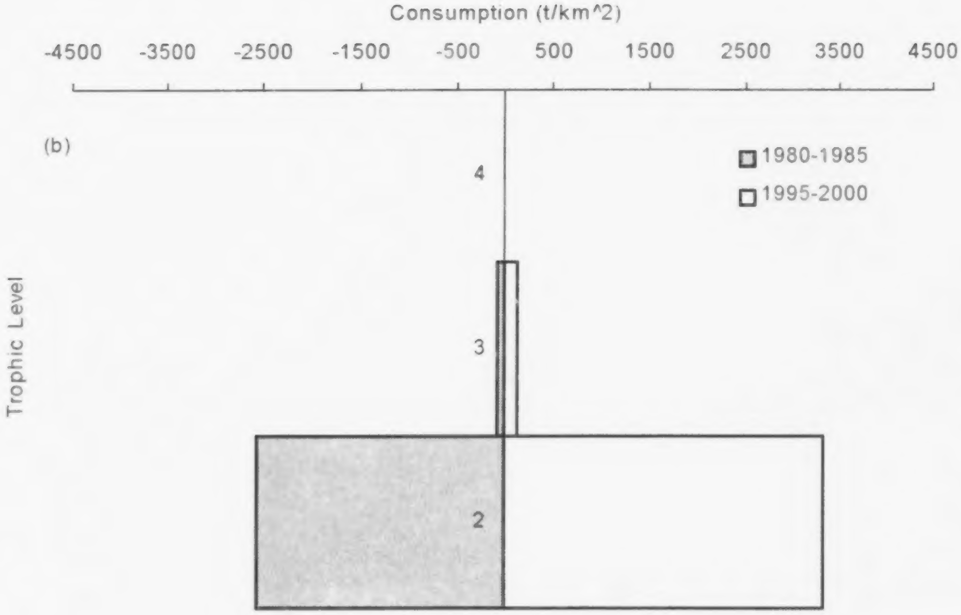


Figure 24. Consumption by trophic level in 1980-1985 and 1995-2000. 1980-1985 data is shown as negative for illustration only. The increase at trophic levels 3 and 4 was significant at the 95% level.

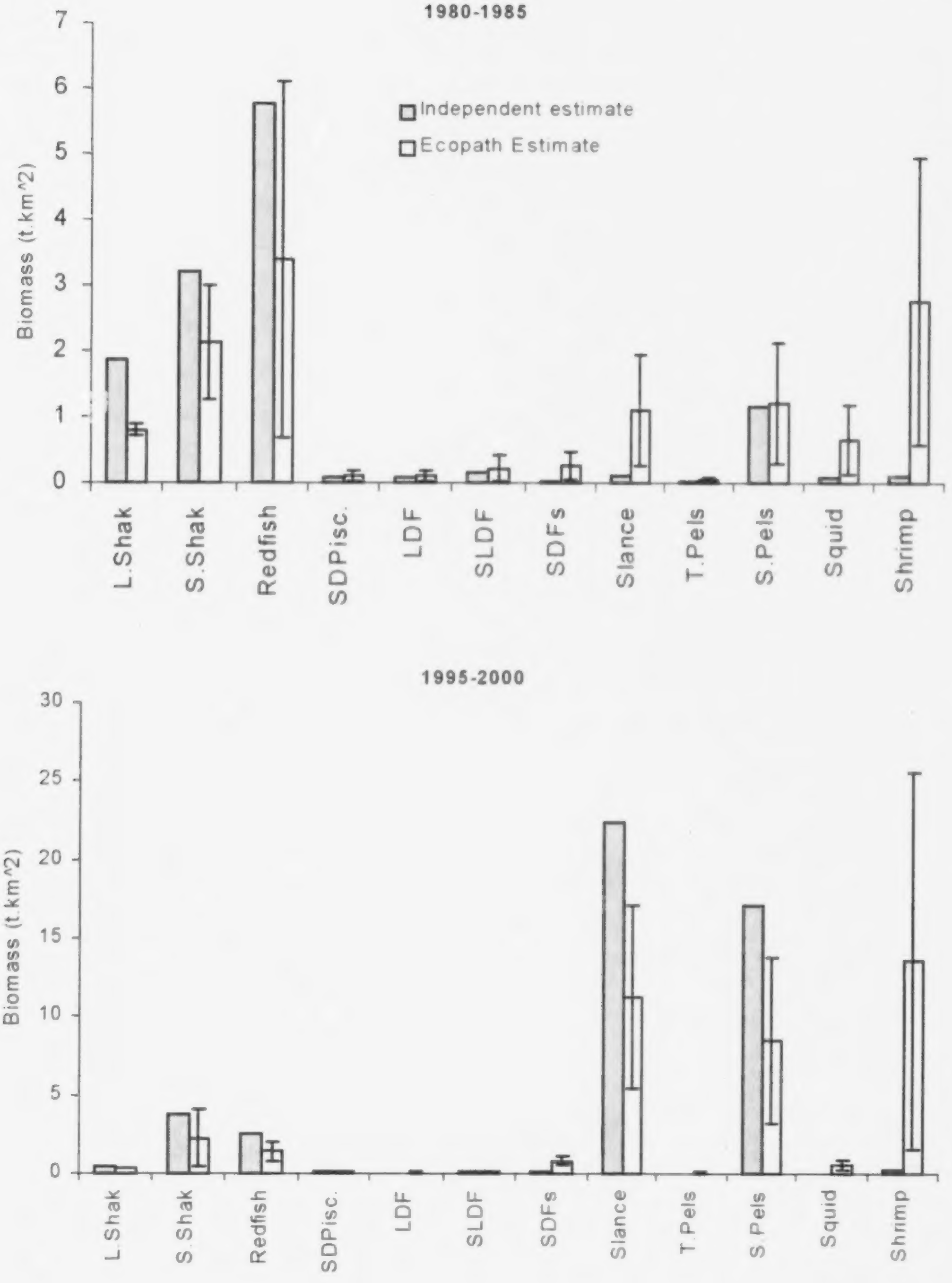


Figure 25. Comparison of independent estimates of biomass with Ecopath estimates of biomass (with 95% confidence limits).

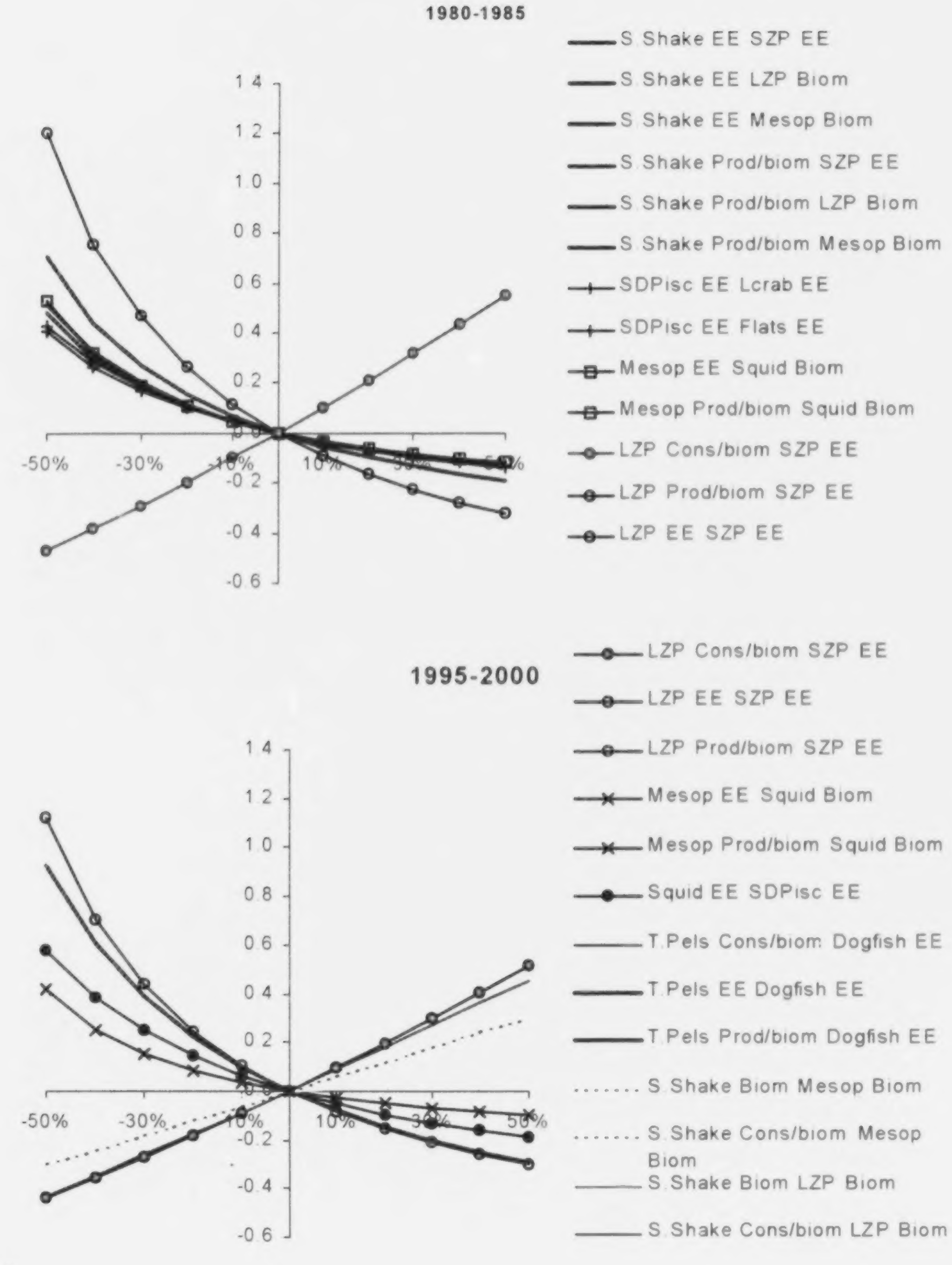


Figure 26. Results of sensitivity analysis for groups parameter estimates that are most sensitive to input parameters.

APPENDIX 1

Table 1. Pedigree ranges describing the percentage uncertainty of each of the parameters for the 1980-1985 model. For example, the range of uncertainty for the biomass of cetaceans is ± 50% of the input biomass estimate.

	Biomass	P/B	Q/B	Diet	Catch
Cetaceans	50	20	20	60	50
Grey Seals	10	10	10	30	50
Seabirds	50	70	40	60	
Large Cod	10	10	20	50	50
Small Cod	30	40	20	60	50
Large Silver Hake	10	10	10	10	50
Small Silver Hake	50	40	10	10	50
Haddock	10	10	20	50	50
American plaice	10	50	20	50	50
Large Halibut	30	50	80	50	50
Small halibut	30	60	30	50	50
Flounders	30	50	80	50	50
Skates	30	50	80	50	50
Dogfish	30	50	30	50	50
Redfish	80	50	30	50	50
Pollock	30	60	30	50	50
Trans. Mackerel	50	40	40	50	50
Large Dem. Piscivores	30	50	30	50	50
Small Dem. Piscivores	80	70	30	50	50
Large Large Demersals	80	50	80	50	50
Small Large Demersals	80	70	80	50	50
Small Demersals	80	70	80	60	50
Capelin	30	60	80	80	50
Sandlance	80	70	80	50	50
Trans. Pelagics	50	70	40	50	50
Small Pelagics	80	20	20	50	50
Small mesopels	80	60	60	60	50
Squid	80	70	20	50	50
Large Crabs	50	50	70	60	50
Small Crabs	80	70	70	60	50
Shrimp	80	50	80	80	50
Echinoderms	50	60	60	60	50
Polychaetes	50	60	60	60	50
Bivalve Mollusc	50	60	60	60	50
OBI	50	60	60	60	50
LZP	80	20	20	60	50
SZP	50	20	80	60	50
Phytoplankton	50	50			

Table 2. Pedigree ranges describing the percentage uncertainty of each of the parameters for the 1995-2000 model. For example, the range of uncertainty for the biomass of cetaceans is ± 50% of the input biomass estimate.

	Biomass	P/B	Q/B	Diet	Catch
Cetaceans	50	20	20	60	50
Grey Seals	10	10	10	30	50
Seabirds	50	70	40	60	50
Large Cod	10	10	20	50	50
Small Cod	30	70	10	50	50
Large Silver Hake	10	10	10	50	50
Small Silver Hake	80	10	10	50	50
Haddock	10	10	20	10	50
American plaice	10	50	20	10	50
Large Halibut	30	50	80	50	50
Small halibut	30	70	10	50	50
Flounders	30	50	40	10	50
Skates	30	50	10	50	50
Dogfish	30	50	20	50	50
Redfish	50	50	20	50	50
Pollock	30	20	20	50	50
Trans. Mackerel	50	40	40	50	50
Large Dem. Piscivores	30	50	40	50	50
Small Dem. Piscivores	30	80	40	50	50
Large Large Demersals	30	50	40	50	50
Small Large Demersals	30	80	40	50	50
Small Demersals	30	80	40	50	50
Capelin	50	80	40	50	50
Sandlance	50	70	80	50	50
Trans. Pelagics	80	70	20	50	50
Small Pelagics	50	20	20	50	50
Small mesopels	80	70	70	60	50
Squid	80	70	20	60	50
Large Crabs	50	50	70	60	50
Small Crabs	50	70	70	60	50
Shrimp	80	50	80	70	50
Echinoderms	50	60	60	60	50
Polychaetes	50	60	60	60	50
Bivalve Mollusc	50	60	60	60	50
OBI	50	60	60	60	50
LZP	50	20	20	60	50
SZP	30	20	80	60	50
Phytoplankton	50	50			

APPENDIX 2

Table 1. Cetacean diets for 1980-1985 and 1995-2000.

	1980-1985								1995-2000
	1	2	3	4	5	6	7	8	9
5 Small Cod	0.000	0.000	0.050	0.000	0.000	0.125	0.000	0.013	0.011
6 Large Silver Hake								0.000	
7 Small Silver Hake	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.008	0.007
8 Haddock								0.000	
9 American plaice								0.000	
10 Large Halibut								0.000	
11 Small halibut								0.000	
12 Flounders	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000
13 Skates								0.000	
14 Dogfish								0.000	
15 Redfish	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.005	0.004
16 Pollock								0.000	
17 Trans. Mackerel	0.00	0.04	0.00	0.00	0.00	0.06	0.10	0.039	0.034
18 Large Dem. Piscivores	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.002	0.002
19 Small Dem. Piscivores	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.002	0.002
20 Large Large Demersals	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.002	0.002
21 Small Large Demersals	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.002	0.002
22 Small Demersals								0.000	
23 Capelin								0.000	
24 Sand lance	0.458	0.056	0.750	0.000	0.000	0.063	0.600	0.150	0.188
25 Trans. Pelagics								0.000	
26 Small Pelagics	0.00	0.04	0.10	0.00	0.05	0.00	0.10	0.040	0.035
27 Small Mesopelagics								0.000	
28 Squid	0.083	0.007	0.050	0.000	0.650	0.750	0.100	0.125	0.120
29 Large Crabs								0.000	
30 Small Crabs								0.000	
31 Shrimp								0.000	
32 Echinoderms								0.000	
33 Polychaetes								0.000	
34 Bivalve Mollusc								0.000	
35 OBI								0.000	
36 LZP	0.458	0.846	0.050	0.487	0.000	0.000	0.000	0.604	0.586
37 SZP	0.000	0.007	0.000	0.513	0.000	0.000	0.000	0.007	0.006
38 Phytoplankton								0.000	
39 Detritus								0.000	
	1	1	1	1	1	1	1	1	

Diet 1. Humpback diet, adapted from the diet in Bundy et al 2001. Capelin were replaced by sand lance and euphausiids
Diet 2. Fin whales diet, whicb was estimated from fin whale stomach content data collected from commercial whale kills on the eastern Scotian Shelf from 1967 to 1972 (Sutcliffe and Brodie (1977)
Diet 3. Minke diet, adapted from the diet in Bundy et al 2001. Capelin was replaced by Sand lance, since capelin, whilst abundance in Newfoundland-Labrador were rarely seen on the eastern Scotian Shelf prior to the early 1990s.
Diet 4. Sei diet whicb was estimated from sei whale stomach content data collected from commercial whale kills on the eastern Scotian Shelf from 1967 to 1972 (Sutcliffe and Brodie (1977)
Diet 5. Sperm diet, adapted from the diet in Bundy et al 2001.
Diet 6. Pilot diet, adapted from the diet in Bundy et al 2001. Capelin was replaced by Sand lance, since capelin, whilst abundance in Newfoundland-Labrador were rarely seen on the eastern Scotian Shelf prior to the early 1990s.
Diet 7. Dolphins diets for the two species of dolphin were estimated from data in Gaskin (1992a,b) and Kenny et al (1997).

Diet 8. Biomass weighted average of the 7 diets.
Diet 9. Diet for the 1995-2000 model, estimated in same way as steps 1-8, but with a greater proportion of humpbacks.

Table 2a. Grey seal diet for the 1980-1985 time period.

Diet	1	2	3
Ecopath Group			
4 Large Cod	2.1	2.4	0.018
5 Small Cod	19.1	21.6	0.166
6 Large Silver Hake	3.1	3.5	0.027
7 Small Silver Hake	16.1	18.1	0.140
8 Haddock	10.6	12.0	0.092
9 American plaice	4.1	4.6	0.035
10 Large Halibut	0	0	0
11 Small halibut	0	0	0
12 Flounders	2.3	2.6	0.020
13 Skates	4.3	4.8	0.037
14 Dogfish	0	0	0
15 Redfish	0	0	0
16 Pollock	0	0	0
17 Trans. Mackerel	1.8	2.0	0.016
18 Large Dem. Piscivores	0	0	0
19 Small Dem. Piscivores	0	0	0
20 Large Large Demersals	0	0	0
21 Small Large Demersals	0	0	0
22 Small Demersals	0	0	0
23 Capelin	0	0	0
24 Sand lance	12.8	14.4	0.111
25 Trans. Pelagics	0	0	0
26 Small Pelagics	6.7	7.6	0.058
27 Small Mesopelagics	0	0	0
28 Squid	4.3	4.3	0.033
29 Large Crabs	0	0	0
30 Small Crabs	4.3	4.3	0.033
31 Shrimp	4.3	4.3	0.033
32 Echinoderms	0	0	0
33 Polychaetes	4.3	4.3	0.033
34 Bivalve Mollusc	4.3	4.3	0.033
35 OBI	14.9	14.9	0.115
36 LZP	0	0	0
37 SZP	0	0	0
38 Phytoplankton	0	0	0
39 Detritus	0	0	0
Total	119.1	129.8	1.0
No. of stomachs with food	47		

Diet 1 is taken from Benoit and Bowen 1990 and converted to Ecopath groups. In order to convert % occurrence to % weight, and in the absence of other information, it was assumed that % occurrence was equivalent to % weight. Data for split pools were split into large and small fish on the basis of mean lengths of prey reported in Bowen et al. (1993).

Diet 2 is diet 1, with unidentified fish were distributed over all fish groups, according to the proportion each group contributed to the total fish.

Diet 3 is diet 2 normalised.

Table 2b. Grey seal diet for the 1995-2000 time period.

	1	2	3	4
4 Large Cod	0.013	0	0.007	0.001
5 Small Cod	0.118	0.004	0.061	0.015
6 Silver hake	0.011	0	0.005	0.005
7 Small Silver Hake	0.056	0	0.028	0.028
8 Haddock	0.009	0	0.005	0.005
9 American plaice	0.065	0	0.032	0.032
10 Large Halibut		0	0.000	0.000
11 Small Halibut		0.001	0.001	0.001
12 Flounders	0.071	0.036	0.054	0.054
13 Skates		0.056	0.028	0.028
14 Dogfish		0	0.000	0.000
15 Redfish	0.011	0.094	0.052	0.052
16 Pollock	0.007	0	0.004	0.004
17 Trans. Mackerel		0	0.000	0.000
18 Large Dem. Piscivores	0.000	0	0.000	0.000
19 Small Dem. Piscivores.	0.003	0	0.002	0.002
20 Large Demersals	0.000	0.002	0.001	0.001
21 Small Large Demersals	0.002	0.015	0.009	0.009
22 Small Demersals	0.015	0.192	0.103	0.103
23 Capelin	0.009	0.392	0.200	0.200
24 Sand lance	0.600	0.113	0.356	0.408
25 Trans. Pelagics		0	0.000	0.000
26 Small Pelagics	0.005	0.012	0.009	0.009
27 Small Mesopelagics		0	0.000	0.000
28 Squid	0.004	0.083	0.044	0.044
29 Large Crabs		0	0.000	0.000
30 Small Crabs		0	0.000	0.000
31 Shrimp		0.001	0.001	0.001
32 Echinoderms		0		
33 Polychaetes		0		
34 Bivalve Mollusc		0		
35 OBI		0		
36 LZP		0		
37 SZP		0		
38 Phytoplankton		0		
39 Detritus		0		
	1.000	1.001	1.000	

Diet 1. Seasonal fecal data from eastern Scotian Shelf, 1991-1998 (Don Bowen, DFO, pers, comm.). Seasons were first averaged across years, then an average of the seasons was taken.

Diet 2. Average diet composition of grey seals using fatty acid analysis (Table 6.4, Beck….).

Diet 3. Average of diets 1 and 2.

Diet 4. Adaptation of Diet 3 based on expert opinion (Don Bowen, DFO, pers, comm.).

Table 3a. Overview of diets (% mass) and field metabolic rates (FMR) for selected seabird species (in alphabetic order) in the North Atlantic, as known from the literature.

Seabird species	Prey species taken	Diet %			FMR (kJ/d)	Reference
		Fat fish	other fish	invertebrates		
Black-legged Kittiwake	75 % capelin, 25 % others	75	0	25	957 (local non-breeders: 617)	Anonymous (2000)
Dovekie	100% zooplankton	0	0	100	276	Anonymous (2000), Brown (1988b)
Great black-backed gull	50% capelin, 10% seabirds, 40% other	50	40	0	1313 (local non-breeders: 853)	Anonymous (2000)
Greater shearwater	30 % zooplankton, 10 % squid, 60 % other (estimated)	25	25	50	870	Anonymous (2000), Diamond (1985), Brown et al. (1981)
Herring gull	51 % capelin, 9% invertebrates, 2% gadoids, 1% squid, 37% others	51	39	10	1887 (local non-breeders: 1238)	Anonymous (2000)
Leach's storm petrel	55% myctophid, 30% amphipods, 10% euphausiid, 5% other	20	0	80	192 (local non-breeders: 114)	Anonymous (2000)
Northern fulmar	50% capelin, 20% squid, 10% discards	70	10	20	1009 (local non-breeders: 807; non-local non-breeders:807)	Anonymous (2000)
Red phalarope	100% zooplankton	0	0 (estimated)	100	300 (estimated)	Brown and Gaskin (1981), Diamond et al. (1983), Mercier and Gaskin (1985)
Sooty shearwater	50% herring, 40% euphausid, 10% other (estimated)	25	25	50	800	Anonymous (2000), Diamond (1985) Brown et al. (1981)
Thick-billed murre	66% daubed shanny, 29% capelin, 2% sandeel, 2% gadoids, 1% other	97	2	1	1648 (local non-breeders: 1078; non-local non-breeders:617)	Anonymous (2000), Gaston (1985)
Wilson's storm petrel	Mostly Zooplankton	20	0	80	98	Anonymous (2000)

Table 3b. Summary of locally adjusted diets (% mass) for seabirds in the Northwest Atlantic unless specified otherwise (EES = eastern Scotian Shelf, WSS = western Scotian Shelf). NB sandeel = sand lance (compiled by Alida Bundy).

Seabird Species	Diets assumed for the model	References
Black-legged kittiwake	ESS: 60% Sand lance, 15% herring, 25% others WSS: 75 % herring, 25% others	6,7
Dovekie	Unchanged (see Table 4)	
Great black-backed gull	ESS: 40% Sand lance, 10% herring, 10% seabirds, 40% other WSS: 50% herring, 10% seabirds, 40% other	9
Greater shearwater	Unchanged (see Table 4)	
Herring gull	ESS: 41 % Sand lance, 10% herring, 9% invertebrates, 2% gadoids, 1% squid, 37% others WSS: 51% herring, 9% invertebrates, 2% gadoids, 1% squid, 37% others	2, 3, 4, 5
Leach's storm-petrel	55% myctophid, 30% amphipods, 10% euphausiid, 5% other	1
Northern fulmar	ESS: 40% Sand lance, 10% herring, 20% squid, 10% discards WSS: 50% herring, 20% squid, 10% discards	9
Red phalarope	Unchanged (see Table 4)	
Sooty shearwater	Unchanged (see Table 4)	
Thick-billed murre	ESS: 66% daubed shanny, 23.3% Sand lance, 5.7 % herring, 2% sandeel, 2% gadoids, 1% other WSS: 66% daubed shanny, 29% herring, 2% small demersals, 2% gadoids, 1% other	8
Wilson's storm petrel	Unchanged (see Table 4)	

Taken from Anonymous (2000 Table 4.5): (1) Montevecchi et al. (1992); (2) Threlfall (1968); (3) Haycock and Threlfall (1975); (4) Pierotti (1983); (5) Brown and Nettleship (1984); (6) Lewis (1957); (7) Regehr (1994); (8) Birkhead and Nettleship (1987); (9) Montevecchi unpubl.

Table A.3c. Final Aggregated Seabird Diet on the eastern Scotian Shelf after adjustment for prey density and relative consumption.

	1980-1985	1995-2000
3 Seabirds	0.0010	0.0010
4 Large Cod		0.0000
5 Small Cod	0.0048	0.0048
6 Silver hake		0.0000
7 Small Silver Hake		0.0000
8 Haddock	0.0048	0.0048
9 American plaice		0.0000
10 Large Halibut		0.0000
11 Small Halibut		0.0000
12 Flounders		0.0000
13 Skates		0.0000
14 Dogfish		0.0000
15 Redfish		0.0000
16 Pollock		0.0000
17 Trans. Mackerel		0.0000
18 Large Dem. Piscivores		0.0000
19 Small Dem. Piscivores.		0.0000
20 Large Demersals		0.0000
21 Small Large Demersals		0.0000
22 Small Demersals	0.0158	0.0079
23 Capelin		0.0010
24 Sand lance	0.1287	0.2756
25 Trans. Pelagics		0.0000
26 Small Pelagics	0.0922	0.0922
27 Small Mesopelagics	0.0083	0.0083
28 Squid	0.0665	0.0100
29 Large Crabs		0.0000
30 Small Crabs	0.0151	0.0151
31 Shrimp	0.0151	0.0151
32 Echinoderms	0.0151	0.0151
33 Polychaetes	0.0151	0.0151
34 Bivalve Mollusc	0.0151	0.0151
35 OBI	0.0151	0.0151
36 LZP	0.4321	0.4321
37 SZP		0.0000
38 Phytoplankton		0.0000
39 Detritus		0.0155
Discards/Import	0.1555	0.0565

1995-2000 diet is based on the 1980-1985 diet. However, sand lance are increased in the diet due the large increase observed in sand lance biomass. Discards are reduced since there has been a groundfish moratoriumon the eastern Scotian Shelf since 1993.

TABLE 4A. LARGE COD DIET, 1980-1985.

	1	2	3	4	5
5 Small Cod	0.004	0.012	0.012	0.012	0.014
6 Silver Hake	0.000	0.000	0.000	0.000	0.000
7 Small Silver Hake	0.011	0.132	0.046	0.070	0.080
8 Haddock	0.003	0.024	0.000	0.009	0.010
9 American plaice	0.007	0.002	0.011	0.002	0.002
10 Halibuts	0.000	0.000	0.000	0.000	0.000
11 Small Halibuts	0.000	0.000	0.000	0.001	0.001
12 Flounders	0.001	0.039	0.006	0.004	0.004
13 Skates	0.000	0.000	0.000	0.000	0.000
14 Dogfish	0.000	0.000	0.000	0.000	0.000
15 Redfish	0.001	0.000	0.014	0.008	0.009
16 Pollock	0.000	0.012	0.017	0.012	0.014
17 Transient Mackerel	0.000	0.000	0.000	0.000	0.000
18 Demersal Piscivores	0.000	0.003	0.020	0.003	0.003
19 Demersal Piscivores	0.000	0.009	0.000	0.009	0.010
20 Large Demersals	0.000	0.007	0.000	0.007	0.008
21 Large Demersals < 30 cm	0.002	0.062	0.000	0.062	0.070
22 Small Demersals	0.006	0.006	0.029	0.006	0.007
23 Capelin	0.005	0.000	0.042	0.000	0.000
24 Sand lance	0.255	0.077	0.129	0.077	0.087
25 Transient Pelagics	0.000	0.000	0.000	0.000	0.000
26 Small Pelagics	0.016	0.141	0.020	0.018	0.020
27 Small Mesopelagics	0.001	0.000	0.000	0.000	0.000
28 Squid	0.011	0.020	0.005	0.008	0.009
29 Large Crabs	0.000	0.001	0.000	0.001	0.001
30 Small Crabs	0.057	0.234	0.212	0.135	0.153
31 Shrimp	0.097	0.074	0.230	0.074	0.085
32 Echinoderms	0.026	0.023	0.062	0.023	0.027
33 Polychaetes	0.028	0.006	0.011	0.028	0.032
34 Bivalve Molluscs	0.128	0.020	0.020	0.020	0.022
35 Other benthic invertebrates	0.046	0.011	0.022	0.046	0.052
36 Zooplankton (large)	0.295	0.036	0.073	0.234	0.266
37 Zooplankton (small)	0.001	0.049	0.020	0.010	0.012
38 Phytoplankton	0.000	0.000	0.000	0.000	0.000
39 Detritus	0.000	0.000	0.000	0.000	0.000
	1.000	1.000	1.000	0.878	1.000

Diet 1. Average annual diet derived from DFO pre-1970s data for the eastern Scotian Shelf (Laurinolli et al 2004)

Diet 2. Average annual diet from the western Scotian Shelf, derived from NMFS surveys (J.Link, NMFS, Pers. Comm).

Diet 3. Average annual diet from eastern Scotian Shelf for the 1990s, derived from DFO stomach sampling for 1999 and 2000 (NB: this is an early version of that used in Table A.5.3).

Diet 4. A subjective amalgam of diets 1 to 3.

Diet 5. Diet 4, normalised.

Table 5. Small cod diet, 1980-1985.

	1960s	1990s	3	4
5 Small Cod	0.000	0.004	0.004	0.004
6 Silver Hake				
7 Small Silver Hake	0.002	0.000	0.002	0.002
8 Haddock				
9 American plaice	0.000	0.000	0.000	0.000
10 Halibuts				
11 Small Halibuts				
12 Flounders				
13 Skates				
14 Dogfish				
15 Redfish	0.001	0.000	0.001	0.001
16 Pollock	0.000	0.002	0.002	0.002
17 Transient Mackerel				
18 Demersal Piscivores				
19 Demersal Piscivores	0.000	0.000	0.000	0.000
20 Large Demersals				
21 Large Demersals < 30 cm	0.001	0.000	0.001	0.001
22 Small Demersals	0.002	0.049	0.002	0.003
23 Capelin	0.039	0.013	0.000	
24 Sand lance	0.097	0.165	0.097	0.100
25 Transient Pelagics				
26 Small Pelagics	0.003	0.022	0.003	0.003
27 Small Mesopelagics				
28 Squid	0.001	0.007	0.001	0.001
29 Large Crabs		0.001	0.000	
30 Small Crabs	0.049	0.137	0.049	0.051
31 Shrimp	0.113	0.308	0.113	0.117
32 Echinoderms	0.020	0.079	0.020	0.021
33 Polychaetes	0.057	0.002	0.057	0.059
34 Bivalve Molluscs	0.048	0.028	0.048	0.049
35 Other benthic invertebrates	0.040	0.042	0.040	0.041
36 Zooplankton (large)	0.507	0.134	0.507	0.525
37 Zooplankton (small)	0.019	0.000	0.019	0.020
38 Phytoplankton				
39 Detritus				
	1.000	0.993	0.967	1.000

Diet 1. Average annual diet derived from DFO pre-1970s data for the eastern Scotian Shelf (Laurinolli et al 2004)

Diet 2. Average annual diet from eastern Scotian Shelf for the 1990s, derived from DFO stomach sampling for 1999 and 2000 (NB: this is an early version of that used in Table A.5.3).

Diet 3. A subjective amalgam of diets 1 to 3.

Diet 4. Diet 4, normalised.

Table 5b. Large and small cod diet, 1995-2000.

PREY	Large cod	Small cod
4 Large Cod		
5 Small Cod	0.084	0.002
6 Silver hake		
7 Small Silver Hake	0.008	0.000
8 Haddock	0.004	0.000
9 American plaice	0.113	0.000
10 Large Halibut		
11 Small Halibut		
12 Flounders	0.009	0.000
13 Skates		
14 Dogfish		
15 Redfish	0.004	0.005
16 Pollock	0.021	0.009
17 Trans. Mackerel	0.000	0.000
18 Dem. Piscivores		
19 Small Dem. Piscivores.		
20 Large Demersals	0.000	0.000
21 Small Large Demersals	0.003	0.001
22 Small Demersals	0.005	0.006
23 Capelin	0.004	0.014
24 Sand lance	0.230	0.154
25 Trans. Pelagics		
26 Small Pelagics	0.146	0.045
27 Small Mesopelagics	0.000	0.000
28 Squid	0.005	0.000
29 Large Crabs	0.000	0.005
30 Small Crabs	0.019	0.028
31 Shrimp	0.288	0.300
32 Echinoderms	0.000	0.000
33 Polychaetes	0.013	0.034
34 Bivalve Mollusc	0.002	0.000
35 OBI	0.013	0.062
36 LZP	0.029	0.333
37 SZP	0.000	0.001
38 Phytoplankton		
39 Detritus		
	1	1

Diet 1. Average annual large cod diet from eastern Scotian Shelf for the 1990s, derived from DFO stomach sampling for 1999 and 2000.

Diet 2. Average annual small cod diet from eastern Scotian Shelf for the 1990s, derived from DFO stomach sampling for 1999 and 2000.

Table 6. Large silver hake diet for 1980-1985 and 1995-2000.

	1980-1985								1995-2000
	1	2	3	4	5	6	7	8	9
4 Large Cod	0.067	0.007	0.003	0	0.046	0.124	0.001	0.001	
5 Small Cod	0	0	0	0	0	0	0	0	0.011
6 Large Silver Hake	8.635	0.922	0.391	0	5.985	15.934	0.159	0.013	
7 Small Silver Hake	0	0	0	0	0	0	0	0.146	0.058
8 Haddock	0.032	0.003	0.001	0.000	0.022	0.060	0.001	0.001	0.059
9 American plaice	0	0	0	0	0	0	0	0	0.000
10 Large Halibut	0	0	0	0	0	0	0	0	
11 Small halibut	0	0	0	0	0	0	0	0	
12 Flounders	0	0	0	0	0	0	0	0	0.000
13 Skates	0	0	0	0	0	0	0	0	
14 Dogfish	0	0	0	0	0	0	0	0	
15 Redfish	0.044	0.005	0	0	0.030	0.079	0.001	0.001	0.000
16 Pollock	0	0	0	0	0	0	0	0	0.007
17 Trans. Mackerel	0	0	0	0	0	0	0	0	0.000
18 Large Dem. Piscivores	0	0	0	0	0	0	0	0	
19 Small Dem. Piscivores	0	0	0	0	0	0	0	0	
20 Large Large Demersals	0	0	0	0	0	0	0	0	0.000
21 Small Large Demersals	0	0	0	0	0	0	0	0	0.000
22 Small Demersals	0	0	0	0	0	0	0	0	0.001
23 Capelin	0	0	0	0	0	0	0	0	0.366
24 Sand lance	0.932	0.100	0	0	0.646	1.678	0.017	0.017	0.148
25 Trans. Pelagics	0	0	0	0	0	0	0	0	
26 Small Pelagics	2.039	0.218	0	0	1.413	3.670	0.037	0.037	0.073
27 Small Mesopelagics	7.815	0.835	0	0	5.417	14.067	0.141	0.141	0.000
28 Squid	16.245	1.735	0	0	0	17.980	0.180	0.180	0.000
29 Large Crabs	0	0	0	0	0	0	0	0	0.000
30 Small Crabs	0	0	0	0	0	0	0	0	0.000
31 Shrimp	0.770	0.082	0	0	0	0.852	0.009	0.009	0.049
32 Echinoderms	0.037	0.004	0	0	0	0.041	0.000	0.000	0.000
33 Polychaetes	0	0	0	0	0	0	0	0	0.000
34 Bivalve Molluscs	0	0	0	0	0	0	0	0	0.000
35 OBI	4.700	0.502	0	0	0	5.202	0.052	0.052	0.000
36 Large Zooplankton	36.263	3.873	0	0	0	40.136	0.402	0.402	0.228
37 Small zooplankton	0.080	0.009	0	0	0	0.089	0.001	0.001	0.000
38 Phytoplankton	0	0	0	0	0	0	0	0	
39 Detritus						0	0	0	
TOTAL	77.661	8.294	0.396	0.000	13.561	99.912	1.000	1.000	1
# stomachs	1805								33

Diet 1 Diet data taken from Table 4.06 (Waldron 1988) for 3+ year old silver hake. It was assumed that Waldron's "Other Pisces" were small pelagics.

Diet 2. Diet adjusted for unidentified remains. The unidentified remains were distributed over all groups relative to that groups total contribution to the diet ie., group a/sum all groups * unid remains.

Diet 3. Adjustment for Other Gadids in the diet. Other Gadids were distributed over the gadid groups, relative to that groups total contribution to the gadids in the diet ie., gadid a/sum all gadid groups * unid gadids.

Diet 4 Adjustement for Other Fish. Unidentified fish were distributed over all the fish groups, relative to that groups total contribution to the fish in the diet ie., fish group a/sum all fish groups * unid fish.

Diet 5 Adjustement for Unidentified Fish. Unidentified fish were distributed over all the fish groups, relative to that groups total contribution to the fish in the diet ie., fish group a/sum all fish groups * unid fish.

Diet 6 Sum of 1 to 5.

Diet 7. Diet 6 normalised.

Diet 8. A large proportion of the consumption of silver hake by silver hake is attributed to small silver hake. This is consistent with the diet data from 1995-2000.

Diet 9. Average annual diet data from DFO Stomach survey, Spring and Summer, 1999 2000

Table 7. Small silver hake diet, 1980-1985 and 1995-2000

	1980-1985						1995-2000
	1	2	3	4	5	6	7
5 Small Cod	0	0	0	0	0	0	0.000
6 Large Silver Hake	0	0	0	0	0	0	
7 Small Silver Hake	1.085	0.129	1.057	0.620	2.890	0.029	0.012
8 Haddock	0	0	0	0	0	0	0.000
9 American plaice	0	0	0	0	0	0	0.000
10 Large Halibut	0	0	0	0	0	0	
11 Small halibut	0	0	0	0	0	0	
12 Flounders	0	0	0	0	0	0	0.000
13 Skates	0	0	0	0	0	0	
14 Dogfish	0	0	0	0	0	0	
15 Redfish	0	0	0	0	0	0	
16 Pollock	0	0	0	0	0	0	0.000
17 Trans. Mackerel	0	0	0	0	0	0	0.012
18 Large Dem. Piscivores	0	0	0	0	0	0	0.000
19 Small Dem. Piscivores	0	0	0	0	0	0	
20 Large Large Demersals	0	0	0	0	0	0	0.000
21 Small Large Demersals	0	0	0	0	0	0	0.000
22 Small Demersals	0	0	0	0	0	0	0.002
23 Capelin	0	0	0	0	0	0	0.017
24 Sand lance	0.237	0.028	0	0.135	0.400	0.004	0.084
25 Trans. Pelagics	0	0	0	0	0	0	
26 Small Pelagics	0.394	0.047	0	0.225	0.666	0.007	0.003
27 Small Mesopelagics	4.337	0.516	0	2.478	7.331	0.073	0.000
28 Squid	2.799	0.333	0	0	3.133	0.031	0.002
29 Large Crabs	0	0	0	0	0	0	0.000
30 Small Crabs	0	0	0	0	0	0	0.000
31 Shrimp	3.547	0.422	0	0	3.970	0.040	0.594
32 Echinoderms	0	0	0	0	0	0	0.000
33 Polychaetes	0.030	0.004	0	0	0.034	0.000	0.000
34 Bivalve Mollusc	0	0	0	0	0	0	0.000
35 OBI	0.624	0.074	0	0	0.698	0.007	0.003
36 Large Zooplankton	72.122	8.583	0	0	80.705	0.808	0.269
37 Small zooplankton	0.100	0.012	0	0	0.112	0.001	0.000
38 Phytoplankton	0	0	0	0	0	0	
39 Detritus						0	
TOTAL	85.276	10.149	1.057	3.458	99.939	1.000	1
# stomachs	1050						474

Diet 1 Diet data taken from Table 4.06 (Waldron 1988) for 0, 1 and 2 year old silver hake. It was assumed that Waldron's "Other Pisces" were small pelagics.

Diet 2. Diet adjusted for unidentified remains. The unidentified remains were distributed over all groups relative to that groups total contribution to the diet ie., group a/sum all groups * unid remains.

Diet 3. Adjustment for Other Gadids in the diet. Other Gadids were distributed over the gadid groups, relative to that groups total contribution to the gadids in the diet ie., gadid a/sum all gadid groups * unid gadids

Diet 4 Adjustment for Unidentified Fish. Unidentified fish were distributed over all the fish groups, relative to that groups total contribution to the fish in the diet ie., fish group a/sum all fish groups * unid fish.

Diet 5 Sum of 1 to 5.

Diet 6. Diet 5 normalised.

Diet 7. Average annual diet data from DFO Stomach survey, Spring and Summer, 1999 2000

Table 8. Haddock Diet in 1980-1985 and 1995-2000

	1980-1985			1995-2000
	1	2	3	4
5 Small Cod	0.000	0.009	0.009	0.0000
6 Silver hake	0.000	0.000	0.000	0.0000
7 Small Silver Hake	0.000	0.009	0.009	0.0007
8 Haddock	0.000	0.009	0.009	0.0005
9 American plaice	0.000	0.001	0.001	0.0000
10 Large Halibut	0.000	0.000	0.000	0.0000
11 Small Halibut	0.000	0.000	0.000	0.0000
12 Flounders	0.000	0.001	0.001	0.0001
13 Skates	0.000	0.000	0.000	0.0000
14 Dogfish	0.000	0.000	0.000	0.0000
15 Redfish	0.000	0.004	0.004	0.0266
16 Pollock	0.000	0.000	0.000	0.0000
17 Trans. Mackerel	0.000	0.000	0.000	0.0000
18 Dem. Piscivores	0.000	0.000	0.000	0.0000
19 Small Dem. Piscivores.	0.000	0.000	0.000	0.0000
20 Large Demersals	0.000	0.000	0.000	0.0000
21 Small Large Demersals	0.000	0.000	0.000	0.0001
22 SmallDemersals	0.005	0.013	0.005	0.0012
23 Capelin	0.000	0.000	0.000	0.0000
24 Sand lance	0.060	0.100	0.060	0.0531
25 Trans. Pelagics	0.000	0.000	0.000	0.0000
26 Small Pelagics	0.000	0.064	0.000	0.0086
27 Small Mesopelagics	0.000	0.000	0.000	0.0001
28 Squid	0.000	0.000	0.000	0.0023
29 Large-Crabs	0.000	0.000	0.000	0.0004
30 SmallCrabs	0.016	0.039	0.015	0.0079
31 Shrimp	0.059	0.066	0.057	0.0294
32 Echinoderms	0.405	0.243	0.390	0.0237
33 Polychaetes	0.102	0.183	0.098	0.4416
34 Bivalves	0.048	0.075	0.046	0.0092
35 OBI	0.078	0.015	0.075	0.1088
36 LZP	0.189	0.164	0.182	0.2858
37 SZP	0.038	0.004	0.037	0.0000
38 Phytoplankton.	0.000	0.000	0.000	0.0000
39 Detritus	0.000	0.000	0.000	0.0000
TOTAL	1.000	1.000	1.000	1.0000

Diet 1. Haddock diet estimated for the area of western Scotian shelf covered by NMFS surveys during the 1980s, n= 463, (J. Link. NMFS Pers. Comm).
Diet 2. Haddock diet estimated from Table 2 in Kohler and Fitzgerald 1969 for NAFO Div 4W on the Scotian Shelf from January to April.
Diet 3. Diet 3 (1980-1985) is diets 1 and 2 combined.
Diet 4. Estimated diet for 1995-2000, from empirical diet studies conducted on the eastern Scotian Shelf 1999 - 2000, n=1336.

Table 9. American plaice diet for 1980-1985 and 1995-2000.

	1980-1985	1995-2000
Prey	1	2
7 Small Silver Hake	0.0060	0
8 Haddock	0.0000	0.0000
9 American plaice	0.0000	0.0007
10 Large Halibut	0.0000	0.0000
11 Small Halibut	0.0000	0.0000
12 Flounders	0.0000	0.0010
13 Skates	0.0000	0.0000
14 Dogfish	0.0000	0.0000
15 Redfish	0.0000	0.0004
16 Pollock	0.0000	0.0000
17 Trans. Mackerel	0.0000	0.0000
18 Large Dem. Piscivores	0.0000	0.0000
19 Small Dem. Piscivores.	0.0000	0.0000
20 Large Large Demersals	0.0000	0.0000
21 Small Large Demersals	0.0000	0.0014
22 Small Demersals	0.0000	0.0007
23 Capelin	0.0000	0.0679
24 Sand lance	0.0000	0.1090
25 Transient Pelagics	0.0000	0.0000
26 Small Pelagics	0.0000	0.0004
27 Small Mesopelagics	0.0000	0.0000
28 Squid	0.0000	0.0012
29 Large Crabs	0.0000	0.0000
30 Small Crabs	0.0280	0.0128
31 Shrimp	0.0290	0.1883
32 Echinoderms	0.7990	0.0419
33 Polychaetes	0.0280	0.2095
34 Bivalves	0.0460	0.0134
35 OBI	0.0170	0.1176
36 LZP	0.0470	0.2338
37 SZP	0.0000	0.0000
38 Phytoplankton.	0.0000	0.0000
39 Detritus	0.0000	0.0000
Sum	1	1

Diet 1. American plaice diet for 1980-1985 estimated for the area of western Scotian shelf covered by NMFS surveys during the 1970s, n= 640, (J. Link. NMFS Pers. Comm).

Diet 2. Estimated diet for 1995-2000, from empirical diet studies conducted on the eastern Scotian Shelf 1999 - 2000, n=727.

Table 10. Large halibut diet for 1980-1985 and 1995-2000.

Prey	1
5 Small Cod	0.0313
6 Silver Hake	0.0000
7 Small Silver Hake	0.0625
8 Haddock	0.0937
9 American plaice	0.1313
10 Halibuts	0.0000
11 Small Halibuts	0.0000
12 Flounders	0.0312
13 Skates	0.0281
14 Dogfish	0.0000
15 Redfish	0.0000
16 Pollock	0.0000
17 Transient Mackerel	0.0000
18 Large Dem. Piscivores	0.0000
19 Small Dem. Piscivores.	0.0625
20 Large Large Demersals	0.0000
21 Small Large Demersals	0.0313
22 Small Demersals	0.0000
23 Capelin	0.0000
24 Sand lance	0.2500
25 Transient Pelagics	0.0000
26 Small Pelagics	0.0875
27 Small Mesopelagics	0.0000
28 Squid	0.0313
29 Large Crabs	0.0000
30 Small Crabs	0.0625
31 Shrimp	0.0938
32 Echinoderms	0.0031
33 Polychaetes	0.0000
34 Bivalve Molluscs	0.0000
35 Other benthic invertebrates	0.0000
36 Large Zooplankton	0.0000
37 Small zooplankton	0.0000
38 Phytoplankton	0.0000
39 Detritus	0.0000

1. Large halibut diet estimated from seasonal RV surveys of the eastern Scotian Shelf from 1960-1967: 1960, winter, n=4; 1961, spring, n=16; 1963, winter, n=4; 1964, winter, n=3; 1965, winter, n=1; 1986, winter, n=3; 1967, summer, n=1. The average diet was weighted by sample size. This diet was used to represent large halibut diet in 1980-1985 and 1995-2000.

Table 11. Small halibut diet for 1980-1985 and 1995-2000.

Prey	1 1980-1985	2 1995-2000
5 Small Cod	0	0
6 Silver Hake	0	0
7 Small Silver Hake	0	0.0030
8 Haddock	0.0054	0.0000
9 American plaice	0.0162	0.0085
10 Halibuts	0	0
11 Small Halibuts	0	0
12 Flounders	0.0068	0.0250
13 Skates	0	0
14 Dogfish	0	0
15 Redfish	0	0.0263
16 Pollock	0	0
17 Transient Mackerel	0	0
18 Large Dem. Piscivores	0	0
19 Small Dem. Piscivores.	0	0
20 Large Large Demersals	0	0
21 Small Large Demersals	0.0182	0.0118
22 Small Demersals	0.0203	0.0218
23 Capelin	0	0.2462
24 Sand lance	0.2730	0.2914
25 Transient Pelagics	0	0
26 Small Pelagics	0	0.0150
27 Small Mesopelagics	0	0
28 Squid	0.0189	0
29 Large Crabs	0	0
30 Small Crabs	0.1426	0.0031
31 Shrimp	0.4662	0.1985
32 Echinoderms	0.0068	0
33 Polychaetes	0.0182	0.0012
34 Bivalve Molluscs	0.0068	0
35 Other benthic invertebrates	0	0
36 Large Zooplankton	0	0.1482
37 Small zooplankton	0	0
38 Phytoplankton	0	0
39 Detritus	0	0
Total	1	1

Diet 1. Average small halibut diet estimated from seasonal RV surveys of the eastern Scotian Shelf from 1960-1967: 1960, winter, n=15; 1961, spring, n=55; 1962, spring, n=52; 1963, winter, n=8; 1964, winter, n=1; 1964, summer, n=11; 1965,spring, n=1; 1966, summer, n=2;. 1967, summer, n=2; 1968, summer, n=1. The average diet was weighted by sample size. This diet was used to represent small halibut diet in 1980-1985.

Diet 2. Average small halibut diet estimated from turbot and Atlantic halibut stomachs collected from summer and spring RV surveys in 1999 and 2000. Spring turbot, n=67, Altantic halibut n=8; Summer turbot n=169, Atlantic halibut n=4. Total n=235.

Diet 3. . Diet 1 (1980-1985) adjusted to included species seen in the 1995-2000 diet. Less than 1%

Table 12. Flounder Diet for 1980-1985 and 1995-2000.

	1980-1985				1995-2000
	1	2	3	4	5
5 Small Cod	0	0	0	0	0.000
6 Silver hake	0	0	0	0	
7 Small Silver Hake	0	0	0	0	0.000
8 Haddock	0	0	0	0	0.000
9 American plaice	0	0	0	0	0.000
10 Large Halibut	0	0	0	0	
11 Small Halibut	0	0	0	0	
12 Flounders	0	0	0	0	0.000
13 Skates	0	0	0	0	
14 Dogfish	0	0	0	0	
15 Redfish	0	0	0	0	0.007
16 Pollock	0	0	0	0	0.000
17 Trans. Mackerel	0	0	0	0	0.000
18 Large Dem. Piscivores	0	0	0	0	
19 Small Dem. Piscivores.	0	0	0	0	
20 Large Large Demersals	0	0	0	0	0.000
21 Small Large Demersals	0	0	0	0	0.000
22 Small Demersals	0	0	0	0	0.000
23 Capelin	0	0	0	0	0.002
24 Sand lance	0	0	0	0	0.052
25 Trans. Pelagics	0	0	0	0	
26 Small Pelagics	0	0	0	0	0.000
27 Small Mesopelagics	0	0	0	0	0.000
28 Squid	0	0	0	0	0.000
29 Large Crabs	0	0	0	0	0.000
30 Small Crabs	0.01	0	0.00	0.00	0.001
31 Shrimp	0.11	0.02	0.00	0.08	0.028
32 Echinoderms	0.02	0.00	0.20	0.05	0.001
33 Polychaetes	0.61	0.75	0.64	0.63	0.417
34 Bivalve Mollusc	0.01	0.01	0.03	0.01	0.007
35 OBI	0.03	0.19	0.05	0.05	0.091
36 Large Zooplankton	0.21	0.03	0.08	0.17	0.393
37 Small zooplankton	0	0	0	0	0.000
38 Phytoplankton	0	0	0	0	
39 Detritus	0	0	0	0	
	1	1	1	1	1

Diet 1. Yellowtail flounder diet from NMFS diet data from the western Scotian Shelf in the 1980s (J. Link, NMFS, pers. comm.). N=67

Diet 2. Winter flounder diet data from NMFS diet data from the western Scotian Shelf in the 1980s (J. Link, NMFS, pers. comm.). N=98

Diet 3. Witch flounder diet data from NMFS diet data from the western Scotian Shelf in the 1970s (J. Link, NMFS, pers. comm.). N=360.

Diet 4. Biomass weighted average flounder diet.

Diet 5. Annual average flounder diet for eastern Scotian Shelf from stomach sampling in 1999 and 2000. N=1313.

Table 13. Skate Diet in 1980-1985 and 1995-2000.

	1980-1985			1995-2000
	1	2	3	4
4 Cod				
5 Small Cod	0.001	0.065	0.050	0.000
6 Silver Hake				
7 Small Silver Hake	0.005	0.004	0.004	0.003
8 Haddock	0.001		0.000	0.000
9 American plaice				0.000
10 Halibuts				
11 Small Halibuts				
12 Flounders	0.004		0.001	0.000
13 Skates	0.002		0.000	
14 Dogfish				
15 Redfish	0.000	0.015	0.011	0.002
16 Pollock				0.000
17 Transient Mackerel	0.002		0.000	0.000
18 Large Dem. Piscivores				
19 Small Dem. Piscivores.				
20 Large Large Demersals				0.000
21 Small Large Demersals	0.001	0.055	0.042	0.002
22 Small Demersals	0.015	0.093	0.075	0.000
23 Capelin				0.004
24 Sand lance	0.281	0.004	0.069	0.100
25 Transient Pelagics				
26 Small Pelagics	0.008		0.002	0.004
27 Small Mesopelagics				
28 Squid	0.015	0.044	0.037	0.001
29 Large Crabs				0.002
30 Small Crabs	0.022	0.147	0.118	0.053
31 Shrimp	0.016	0.070	0.058	0.086
32 Echinoderms				
33 Polychaetes	0.331	0.426	0.404	0.141
34 Bivalve Molluscs	0.235	0.001	0.056	
35 Other benthic invertebrates	0.024	0.021	0.021	0.108
36 Large Zooplankton	0.030	0.037	0.035	0.493
37 Small zooplankton	0.007	0.018	0.015	
38 Phytoplankton				
39 Detritus				
			1	1

Diet 1. Winter skate diet from NMFS diet data from Georges Bank and the western Scotian Shelf in the 1980s (J. Link, NMFS, pers. comm.) N=2360
Diet 2. Thorny skate diet from NMFS diet data from Georges Bank and the western Scotian Shelf in the 1980s (J. Link, NMFS, pers. comm.). N=221.
Diet 3. Biomass weighted average of diets 1 and 2.
Diet 4. Annual average skate (thorny, winter and smooth skates) diet for eastern Scotian Shelf from stomach sampling in 1999 and 2000. N=404

Table 14. Spiny dogfish diet for 1980-1985 and 1995-2000.

	1	2
4 Cod	0.0053	0
5 Small Cod	0.0212	0.0055
6 Silver Hake	0.0107	0
7 Small Silver Hake	0.0428	0.1991
8 Haddock	0.0000	0.0163
9 American plaice	0.0027	0.1418
10 Halibuts	0.0000	0
11 Small Halibuts	0.0000	0
12 Flounders	0.0429	0.0062
13 Skates	0.0002	0
14 Dogfish	0.0000	0
15 Redfish	0.0000	0.0136
16 Pollock	0.0000	0.0000
17 Transient Mackerel	0.0627	0.0013
18 Large Dem. Piscivores	0.0024	0
19 Small Dem. Piscivores.	0.0095	0
20 Large Large Demersals	0.0108	0.0000
21 Small Large Demersals	0.0431	0.0000
22 Small Demersals	0.0256	0.0001
23 Capelin	0.0000	0.0000
24 Sand lance	0.2183	0.0387
25 Transient Pelagics	0.0000	0
26 Small Pelagics	0.0313	0.2642
27 Small Mesopelagics	0.0007	0.0000
28 Squid	0.0926	0.0403
29 Large Crabs	0.0000	0.0000
30 Small Crabs	0.0187	0.0000
31 Shrimp	0.0171	0.0925
32 Echinoderms	0.0004	0.0000
33 Polychaetes	0.0080	0.0000
34 Bivalve Molluscs	0.0326	0.0000
35 Other benthic invertebrates	0.0072	0.1788
36 Large Zooplankton	0.2803	0.0016
37 Small zooplankton	0.0132	0.0000
38 Phytoplankton	0.0000	0.0000
39 Detritus	0.0000	0.0000

Diet 1. Average annual diet for 1980-1985 estimated from seasonal 5825 stomach samples collected from Georges Bank during the 1980s (J. Link. Pers. Comm).
Diet 2. Average annual diet estimated from 82 stomach samples collected from spring and summer survey on the eastern Scotian Shelf in 1999 and 2000.

Table 15. Redfish Diet for 1980-1985 and 1995-2000.

	1	2
4 Cod	0	0
5 Small Cod	0	0
6 Silver Hake	0	0
7 Small Silver Hake	0	0
8 Haddock	0	0
9 American plaice	0	0
10 Halibuts	0	0
11 Small Halibuts	0	0
12 Flounders	0	0
13 Skates	0	0
14 Dogfish	0	0
15 Redfish	0	0.0022
16 Pollock	0	0
17 Transient Mackerel	0	0
18 Large Dem. Piscivores	0	0
19 Small Dem. Piscivores.	0	0
20 Large Large Demersals	0	0
21 Small Large Demersals	0	0
22 Small Demersals	0	0.0057
23 Capelin	0	0
24 Sand lance	0	0.0008
25 Transient Pelagics	0	0
26 Small Pelagics	0	0
27 Small Mesopelagics	0	0.0306
28 Squid	0	0.0041
29 Large Crabs	0	0
30 Small Crabs	0	0
31 Shrimp	0.2786	0.5687
32 Echinoderms	0	0
33 Polychaetes	0.0005	0
34 Bivalve Molluscs	0	0
35 Other benthic invertebrates	0.0080	0.1171
36 Large Zooplankton	0.6731	0.2664
37 Small zooplankton	0.0398	0.0044
38 Phytoplankton	0	0
39 Detritus	0	0
Total	1	1

Diet 1. Average annual redfish diet for 1980-1985 estimated for the area of western Scotian shelf covered by NMFS surveys during the 1970s, n= 171 and 1980s, n=100, (J. Link. NMFS Pers. Comm).

Diet 2. Estimated diet for 1995-2000, from empirical diet studies conducted on the eastern Scotian Shelf 1999 - 2000, n=137. In this diet, several fish species are eaten whereas none are in the diet from the western Scotian Shelf for the 1970s and 1980s.

Table 16.Pollock Diet for 1980-1985 and 1995-2000.

	1	2
5 Small Cod		0.0013
6 Large Silver Hake		
7 Small Silver Hake	0.1155	0.0291
8 Haddock	0	0.0617
9 American plaice	0	0
10 Large Halibut	0	
11 Small halibut	0	
12 Flounders		0.00006
13 Skates		
14 Dogfish		
15 Redfish	0.0159	0.0839
16 Pollock	0	0.0012
17 Trans. Mackerel		0
18 Large Dem. Piscivores		
19 Small Dem. Piscivores	0.00	
20 Large Large Demersals	0.00	0
21 Small Large Demersals		0
22 Small Demersals	0.000	0
23 Capelin		0
24 Sand lance	0.054	0.0506
25 Trans. Pelagics		
26 Small Pelagics	0.092	0.1542
27 Small Mesopelagics	0.020	0.0022
28 Squid	0.008	0.0242
29 Large Crabs		0
30 Small Crabs	0.000	0.0051
31 Shrimp	0.032	0.1491
32 Echinoderms	0.000	0
33 Polychaetes	0.011	0.0001
34 Bivalve Mollusc	0.000	0
35 OBI	0.000	0.0102
36 Large Zooplankton	0.631	0.4270
37 Small zooplankton	0.021	0
38 Phytoplankton	0	0
39 Detritus	0	0
Total	1	1

Diet 1. Average annual pollock diet for 1980-1985. This is the average from 3 winter surveys (1983-1985, n=238) and a summer survey in 1988 (n=97).
Diet 2. Estimated diet for 1995-2000, from empirical diet studies conducted on the eastern Scotian Shelf 1999 - 2000, n=141.

Table 17. Transient Mackerel Diet for 1980-1985 and 1995-2000

	1980-1985 and 1995-2000				
	1	2	3	4	5
5 Small Cod	0	0	0	0	0
6 Large Silver Hake	0	0	0	0	0
7 Small Silver Hake	0	0	0	0	0
8 Haddock	0	0	0	0	0
9 American plaice	0	0	0	0	0
10 Large Halibut	0	0	0	0	0
11 Small halibut	0	0	0	0	0
12 Flounders	0	0	0	0	0
13 Skates	0	0	0	0	0
14 Dogfish	0	0	0	0	0
15 Redfish	0	0	0	0	0
16 Pollock	0	0	0	0	0
17 Trans. Mackerel	0	0	0	0	0
18 Large Dem. Piscivores	0	0	0	0	0
19 Small Dem. Piscivores	0	0	0	0	0
20 Large Large Demersals	0	0	0	0	0
21 Small Large Demersals	0	0	0	0	0
22 Small Demersals	0	0	0	0	0
23 Capelin	0	0	0	0	0
24 Sand lance	0	0	0	0	0
25 Trans. Pelagics	0	0	0	0	0
26 Small Pelagics	0	0	0	0.250	0.083
27 Small Mesopelagics	0	0	0	0	0
28 Squid	0	0	0	0	0
29 Large Crabs	0	0	0	0	0
30 Small Crabs	0	0	0	0	0
31 Shrimp	0	0	0	0.083	0.028
32 Echinoderms	0	0	0	0	0
33 Polychaetes	0	0	0	0	0
34 Bivalve Mollusc	0	0	0	0	0
35 OBI	0	0	0	0	0
36 Large Zooplankton	0.790	0.975	0.195	0.583	0.585
37 Small zooplankton	0.020	0.025	0.805	0.083	0.304
38 Phytoplankton	0	0	0	0	0
39 Detritus	0	0	0	0	0
Total	0.810	1	1	1	1
# stomachs	14	14	33		

Diet 1 is from the edge of the Scotian Shelf, winter 1976, (Kulka and Stobo 1981
Diet 2 is diet 1 normalised
Diet 3 is from Emerald Basin (Gregoire and Castonguay 1989).
Diet 4 is from the edge of the Scotian Shelf, in Spring and Autumn, year?, MacKay (1979).
Diet 5 is the average of diets 2 to 4.

Table 18a. Diet of Large demersal piscivores for 1980-1985.

	1	2	3	4	5
4 Cod	-	0.048	-	0.009	0.009
5 Small Cod	-	0.226	0.297	0.057	0.057
6 Large Silver Hake	-	0.059	0.000	0.011	0.011
7 Small Silver Hake	0.591	0.170	0.004	0.483	0.483
8 Haddock	0.036	0.037	0.175	0.043	0.042
9 American plaice	0.006	0.013	0.247	0.019	0.019
10 Large Halibut	-	-	-	-	-
11 Small halibut	-	-	-	-	0.001
12 Flounders	0.012	0.027	0.030	0.016	0.016
13 Skates	-	0.103	-	0.019	0.019
14 Dogfish	-	0.016	-	0.003	0.003
15 Redfish	0.127	-	-	0.097	0.097
16 Pollock	0.024	0.034	0.001	0.025	0.025
17 Trans. Mackerel	-	0.021	-	0.004	0.004
18 Large Dem. Piscivores	-	0.018	-	0.004	0.004
19 Small Dem. Piscivores	0.012	0.077	0.001	0.024	0.024
20 Large Large Demersals	-	0.005	-	0.001	0.001
21 Small Large Demersals	0.046	0.011	-	0.038	0.038
22 Small Demersals	-	0.029	0.228	0.017	0.017
23 Capelin	-	-	-	-	-
24 Sand lance	-	0.000	0.013	0.001	0.001
25 Trans. Pelagics	-	-	-	-	-
26 Small Pelagics	0.045	0.076	-	0.048	0.048
27 Small Mesopelagics	-	-	-	-	-
28 Squid	0.009	0.028	0.001	0.012	0.012
29 Large Crabs	-	-	-	-	-
30 Small Crabs	-	-	0.002	0.000	0.000
31 Shrimp	0.081	0.000	0.000	0.062	0.062
32 Echinoderms	-	0.000	-	-	-
33 Polychaetes	-	-	0.000	-	-
34 Bivalve Mollusc	-	0.002	-	0.000	0.000
35 OBI	0.009	-	0.001	0.007	0.007
36 Large Zooplankton	-	-	-	-	-
37 Small zooplankton	-	-	-	-	-
38 Phytoplankton	-	-	-	-	-
39 Detritus	-	-	-	-	-
Total	1	1	1	1	1

Diet 1. White hake diet for the eastern Scotian Shelf from the Pollock survey, December 1984, n=104.

Diet 2. Monkfish diet from George's Bank and portion of western Scotian Shelf surveyed by NMFS for 1980s and 1990s, where n=140 and 358 for Georges Bank in 1980s and 1990s respectively and n=40 for western Scotian Shelf in 1980s (J. Link, NMFS, pers. Comm). The three diets were average without weighting.

Diet 3. Sea raven diet from portion of western Scotian Shelf surveyed by NMFS for 1980s where n=111 (J. Link, NMFS, pers. Comm).

Diet 4. Average of diets 1-3, weighted by the q-adjusted biomass.

Diet 5. Diet 4, with 0.1 % Small halibut added. This is seen in the monkfish diet in Newfoundland (Bundy et al 2001) and is likely to be present in the monkfish diet on the eastern Scotian Shelf too.

Table 18b. Diet of Large demersal piscivores for 1995-2000.

	1
4 Cod	
5 Small Cod	0.0210
6 Large Silver Hake	
7 Small Silver Hake	0.1308
8 Haddock	0.1807
9 American plaice	0.0000
10 Large Halibut	
11 Small halibut	
12 Flounders	0.0916
13 Skates	
14 Dogfish	
15 Redfish	0.0158
16 Pollock	0.0008
17 Trans. Mackerel	0.0000
18 Large Dem. Piscivores	
19 Small Dem. Piscivores	
20 Large Large Demersals	0.0733
21 Small Large Demersals	0.0378
22 Small Demersals	0.0132
23 Capelin	0.0000
24 Sand lance	0.0469
25 Trans. Pelagics	
26 Small Pelagics	0.1720
27 Small Mesopelagics	0.0000
28 Squid	0.0787
29 Large Crabs	0.0009
30 Small Crabs	0.0029
31 Shrimp	0.1242
32 Echinoderms	0.0000
33 Polychaetes	0.0000
34 Bivalve Mollusc	0.0000
35 OBI	0.0086
36 Large Zooplankton	0.0007
37 Small zooplankton	0.0000
38 Phytoplankton	0.0000
39 Detritus	0.0000
Total	

Diet 1. . Diet for the demersal piscivores estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000. White hake, n=72; Sea raven, n=12, Monkfish n=13, total n=97. Since the sample sizes are small for all three species, the stomachs were pooled for the spring and summer, and then an average taken of the spring and summer pooled diet.

Table 19a. Diet of Small demersal piscivores for 1980-1985 and 1995-2000.

	1980-1985				1995-2000
	1	2	3	4	5
4 Cod	-	-	-	-	-
5 Small Cod	-	0.054	0.107	0.096	0.054
6 Large Silver Hake	-	-	-	-	
7 Small Silver Hake	0.429	0.060	0.214	0.192	0.060
8 Haddock	-	0.030	0.030	0.027	0.030
9 American plaice	-	0.026	0.026	0.023	0.026
10 Large Halibut	-	-	-	-	
11 Small halibut	-	-	-	-	
12 Flounders	-	0.097	0.097	0.087	0.097
13 Skates	-	-	-	-	
14 Dogfish	-	-	-	-	
15 Redfish	-	0.042	0.042	0.038	0.042
16 Pollock	-	0.001	0.001	0.001	0.001
17 Trans. Mackerel	-	-	-	-	-
18 Large Dem. Piscivores	-	-	-	-	
19 Small Dem. Piscivores	-	-	-	-	
20 Large Large Demersals	-	0.005	0.005	0.005	0.005
21 Small Large Demersals	-	0.057	0.057	0.051	0.057
22 Small Demersals	-	0.010	0.010	0.009	0.010
23 Capelin	-	-	-	-	-
24 Sand lance	-	0.045	0.004	0.004	0.045
25 Trans. Pelagics	-	-	-	-	-
26 Small Pelagics	-	0.058	0.006	0.005	0.058
27 Small Mesopelagics	-	-	-	-	-
28 Squid	-	0.053	0.053	0.047	0.053
29 Large Crabs	-	0.009	0.009	0.008	0.009
30 Small Crabs	0.071	0.014	0.014	0.012	0.014
31 Shrimp	0.500	0.331	0.331	0.296	0.331
32 Echinoderms	-	-	-	-	-
33 Polychaetes	-	0.012	0.012	0.011	0.012
34 Bivalve Mollusc	-	0.001	0.001	0.001	0.001
35 OBI	-	0.051	0.051	0.046	0.051
36 Large Zooplankton	-	0.046	0.046	0.042	0.046
37 Small zooplankton	-	-	-	-	-
38 Phytoplankton	-	-	-	-	-
39 Detritus	-	-	-	-	-
Total	1	1	1.12	1	1

Diet 1. Small white hake diet for the eastern Scotian Shelf from the Pollock survey, December 1984, n=14.

Diet 2. Diet for the demersal piscivores estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 - 2000, n=273. For more details see Table 18.d.

Diet 3. Diet 1 from 1984 has too small a sample size to be used to represent the Small demersal piscivores diet for the 1980-1985. In lieu of more diet data from the period, Diet 2, is adjusted for species abundance differences between the 1980s and 1995-2000: Small cod is doubled; half the value of Small silver hake from Diet 1, 1/10 of the sand lance and 1/10 of the capelin.

Diet 4. Diet 3 normalised.

Diet 5. Diet for the Small demersal piscivores estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000. White hake, n=202; Sea raven, n=31, Monkfish n=40, total n=273. Since the sample sizes are small two of the three species, the stomachs were pooled for the spring and summer, and then an average taken of the spring and summer pooled diet.

Table 20a. Diet of Large large demersals (> 30 cm), 1980-1985.

	1	2	3	4	5	6
4 Cod	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5 Small Cod	0.0000	0.0161	0.0000	0.0000	0.0053	0.0050
6 Large Silver Hake	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7 Small Silver Hake	0.0000	0.1445	0.0000	0.0000	0.0473	0.0469
8 Haddock	0.0000	0.0811	0.0000	0.0000	0.0266	0.0269
9 American plaice	0.0102	0.0000	0.0000	0.0000	0.0051	0.0050
10 Large Halibut	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11 Small halibut	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12 Flounders	0.0000	0.0013	0.0000	0.0000	0.0004	0.0000
13 Skates	0.0035	0.0000	0.0000	0.0000	0.0017	0.0020
14 Dogfish	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15 Redfish	0.1438	0.0000	0.0000	0.0000	0.0714	0.0708
16 Pollock	0.0000	0.0000	0.0000	0.0000	0.0000	0.0020
17 Trans. Mackerel	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18 Large Dem. Piscivores	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19 Small Dem. Piscivores	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20 Large Large Demersals	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21 Small Large Demersals	0.0000	0.0562	0.0000	0.0000	0.0184	0.0179
22 Small Demersals	0.0000	0.0018	0.0000	0.0000	0.0006	0.0010
23 Capelin	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24 Sand lance	0.0000	0.1314	0.0000	0.0000	0.0430	0.0429
25 Trans. Pelagics	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26 Small Pelagics	0.0000	0.0174	0.0110	0.0000	0.0067	0.0070
27 Small Mesopelagics	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28 Squid	0.0000	0.0679	0.0000	0.0000	0.0222	0.0219
29 Large Crabs	0.0004	0.0056	0.0000	0.0000	0.0020	0.0020
30 Small Crabs	0.0585	0.0329	0.0000	0.0307	0.0424	0.0429
31 Shrimp	0.0130	0.1667	0.2410	0.0010	0.0833	0.0828
32 Echinoderms	0.4004	0.0002	0.0030	0.7877	0.2654	0.2682
33 Polychaetes	0.0033	0.0147	0.0000	0.0028	0.0067	0.0070
34 Bivalve Mollusc	0.2892	0.0485	0.0000	0.0816	0.1662	0.1665
35 OBI	0.0756	0.0454	0.0000	0.0274	0.0547	0.0548
36 Large Zooplankton	0.0023	0.1379	0.7350	0.0103	0.1148	0.1147
37 Small zooplankton	0.0000	0.0305	0.0000	0.0095	0.0108	0.0110
38 Phytoplankton	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39 Detritus	0.0000	0.0000	0.0100	0.0490	0.0051	0.0010
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1

Diet 1. Wolffish data were taken from Bundy et al (2001) where wolffish diet was estimated from diet studies by Templeman (1985) in the northwest Atlantic and Keats et al (1986) and Albikovskaya (1983) from Newfoundland waters.

Diet 2. Red hake diet from George's Bank and portion of western Scotian Shelf surveyed by NMFS for 1980s, where n=1242 and 149 respectively (J. Link, NMFS, pers. Comm).

Diet 3. Longfin hake diet was taken from Langton and Bowman 1980.

Diet 4. Ocean pout deit data from George's Bank for 1970s, where n=185 (J. Link, NMFS, pers. Comm).

Diet 5. Average of diets 1-4, weighted by the q-adjusted biomass.

Diet 6. Diet 5 (1980-1985) diet adjusted to included species seen in the 1995-2000 diet. Less than 1% of the prey item is added to the diet by multiplying the 1980-1985 value by 1,1/10 or 1/100. The diet is then normalised.

Table 20b. Diet of Large large demersals (> 30 cm), 1995-2000.

	1
4 Cod	0.0000
5 Small Cod	0.0241
6 Large Silver Hake	0.0000
7 Small Silver Hake	0.0000
8 Haddock	0.0000
9 American plaice	0.0201
10 Large Halibut	0.0000
11 Small halibut	0.0000
12 Flounders	0.0000
13 Skates	0.0000
14 Dogfish	0.0000
15 Redfish	0.0010
16 Pollock	0.0020
17 Trans. Mackerel	0.0000
18 Large Dem. Piscivores	0.0000
19 Small Dem. Piscivores	0.0000
20 Large Large Demersals	0.0000
21 Small Large Demersals	0.0000
22 Small Demersals	0.0189
23 Capelin	0.0000
24 Sand lance	0.0499
25 Trans. Pelagics	0.0000
26 Small Pelagics	0.0000
27 Small Mesopelagics	0.0000
28 Squid	0.0000
29 Large Crabs	0.0100
30 Small Crabs	0.1263
31 Shrimp	0.2764
32 Echinoderms	0.0871
33 Polychaetes	0.1349
34 Bivalve Mollusc	0.0134
35 OBI	0.1416
36 Large Zooplankton	0.0944
37 Small zooplankton	0.0000
38 Phytoplankton	0.0000
39 Detritus	0.0000
Total	1

Diet 1. . Diet for the Large large demersals estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000. Red hake, n=13; wolffish=23, eelpout=10, Vahl's eelpout=17, total n=63.

Table A. 21. Diet of Small large demersals (≤ 30 cm) in 1980-1985 and 1995-2000.

	1980-1985		1995-2000
	1	2	3
4 Cod			
5 Small Cod	0.0241	0.0241	0.0241
6 Large Silver Hake			
7 Small Silver Hake	0.0000		0.0000
8 Haddock	0.0000		0.0000
9 American plaice	0.0201	0.0201	0.0201
10 Large Halibut			
11 Small halibut			
12 Flounders	0.0000		0.0000
13 Skates			
14 Dogfish			
15 Redfish	0.0010	0.0010	0.0010
16 Pollock	0.0020	0.0020	0.0020
17 Trans. Mackerel	0.0000		0.0000
18 Large Dem. Piscivores			
19 Small Dem. Piscivores			
20 Large Large Demersals	0.0000		0.0000
21 Small Large Demersals	0.0000		0.0000
22 Small Demersals	0.0189	0.0047	0.0189
23 Capelin	0.0000		0.0000
24 Sand lance	0.0000		0.0000
25 Trans. Pelagics			
26 Small Pelagics	0.0000		0.0000
27 Small Mesopelagics	0.0000		0.0000
28 Squid	0.0000		0.0000
29 Large Crabs	0.0000		0.0000
30 Small Crabs	0.0315	0.0189	0.0315
31 Shrimp	0.2593	0.1559	0.2593
32 Echinoderms	0.0370	0.0445	0.0370
33 Polychaetes	0.2949	0.3546	0.2949
34 Bivalve Mollusc	0.0491	0.0591	0.0491
35 OBI	0.0289	0.0347	0.0289
36 Large Zooplankton	0.2332	0.2804	0.2332
37 Small zooplankton	0.0000		0.0000
38 Phytoplankton			
39 Detritus			
Total	1.0000	1.0000	

Diet 1. 1995-2000 diet for the Small large demersals estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000. Red hake, n=45; wolffish=18, Vahl's eelpout=69, eelpout=4, total n=136.

Diet 2. Diet 1 adjusted to represent the diet in the 1980s. The small demersals are reduced by 75%, and the small crabs by 40%, and the difference attributed proportionally to the other invertebrates groups present in the diet.

Diet 3. 1995-2000 diet for the Small large demersals estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000. Red hake, n=45; wolffish=18, Vahl's eelpout=69, eelpout=4, total n=136.

Table 22a. Diet of small demersals, 1980-1985.

	1	2	3
4 Cod	0	0	0
5 Small Cod	0	0	0
6 Large Silver Hake	0	0	0
7 Small Silver Hake	0	0.022	0.002
8 Haddock	0	0	0
9 American plaice	0	0	0
10 Large Halibut	0	0	0
11 Small halibut	0	0	0
12 Flounders	0	0	0
13 Skates	0	0.004	0.000
14 Dogfish	0	0	0
15 Redfish	0	0	0
16 Pollock	0	0	0
17 Trans. Mackerel	0	0	0
18 Large Dem. Piscivores	0	0	0
19 Small Dem.Piscivores	0	0	0
20 Large Large Demersals	0	0	0
21 Small Large Demersals	0	0.010	0.001
22 Small Demersals	0.010	0.026	0.012
23 Capelin	0	0	0
24 Sand lance	0.010	0.037	0.013
25 Trans. Pelagics	0	0	0
26 Small Pelagics	0.005	0	0.005
27 Small Mesopelagics	0	0	0
28 Squid	0	0	0
29 Large Crabs	0	0	0
30 Small Crabs	0.010	0.176	0.027
31 Shrimp	0.020	0.324	0.050
32 Echinoderms	0.100	0	0.09
33 Polychaetes	0.200	0.084	0.188
34 Bivalve Mollusc		0.076	0.008
35 OBI	0.520	0.093	0.477
36 Large Zooplankton	0.075	0.086	0.076
37 Small zooplankton	0.050	0.061	0.051
38 Phytoplankton		0	0
39 Detritus		0	0
Total			

Diet 1. Small demersal diet taken from Bundy et al (2000), Appendix 2, Table 11.
Diet 2. Longhorn sculpin diet data from NMFS diet data from George's Bank and the western Scotian Shelf in the 1980s (J. Link, NMFS, pers. comm.). N=769.
Diet 3. Biomass weighted average of diets 1 and 2.

Table 22b. Diet of small demersals, 1995-2000.

		1	2	3	4
5	Small Cod		0.0001	0.001	0.001
6	Large Silver Hake				
7	Small Silver Hake		0.0019	0.024	0.015
8	Haddock				
9	American Plaice				
10	Large Halibut				
11	Small Halibut				
12	Flounders		0.0009	0.011	0.007
13	Skates				
14	Dogfish				
15	Redfish		0.0006	0.008	0.005
16	Pollock		0.0001	0.002	0.001
17	Trans. Mackerel				
18	Large Dem. Piscivores				
19	Small Dem.Piscivores				
20	Large Large Demersals				
21	Small Large Demersals		0.0023	0.029	0.018
22	Small Demersals		0.0004	0.006	0.004
23	Capelin		0.0004	0.004	0.003
24	Sand lance		0.0471	0.581	0.370
25	Trans. Pelagics				
26	Small Pelagics		0.0001	0.001	0.001
27	Small Mesopelagics				
28	Squid			0.003	0.002
29	Large Crabs				
30	Small Crabs	0.018	0.018	0.056	0.041
31	Shrimp	0.116	0.116	0.075	0.091
32	Echinoderms	0.024	0.024	0.000	0.009
33	Polychaetes	0.052	0.052	0.037	0.043
34	Bivalve Mollusc	0.000	0.000	0.001	0.001
35	OBI	0.000	0.000	0.043	0.026
36	Large Zooplankton	0.726	0.726	0.119	0.359
37	Small zooplankton	0.001	0.001		0.000
38	Phytoplankton	0.010	0.010		0.004
39	Detritus				
	Fish	0.054			
	Total	1	1.000	1	1

Diet 1. Aggregate small demersal diet estimated from data in Jeff Hutchings (Dalhousie University) report to the Centre for Marine Biodiversity (http://www. marine biodiversity.ca/en/research-funded.html#ecology) for alligator fish, 4-line snake blennie, Altantic spiny lumpsucker and white barracudina, n=357. A simple average diet was estimated for these species.

Diet 2. Diet 2, with fish distributed across species in same relative proportions as in diet 3.

Diet 3. Longhorn sculpin diet estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000, n=241.

Diet 4. Biomass weighted average of Diets 3 and 4.

Table 23. Capelin diet for 1980-1985 and 1995-2000.

	1980-1985	1995-2000
	1	2
23 Capelin	0.01	0.035
24 Sand lance	0.01	0.000
25 Trans. Pelagics		
26 Small Pelagics		0.000
27 Small Mesopelagics		0.000
28 Squid		0.000
29 Large Crabs		0.000
30 Small Crabs		0.000
31 Shrimp		0.362
32 Echinoderms		0.000
33 Polychaetes		0.293
34 Bivalve Mollusc		0.000
35 OBI		0.000
36 LZP	0.434	0.309
37 SZP	0.546	0.000
38 Phytoplankton		
39 Detritus		
Total		
	1	1

Diet 1. Capelin diet from Newfoundland-Labrador model presented in Bundy et al (2000 Appendix 2, Table 12).

Diet 2. Capelin diet estimated from empirical diet studies conducted on the eastern Scotian Shelf 1999 – 2000, n=114.

Table 24. Sand lance Diet.

	1	2
15 Redfish		0.002
16 Pollock		
17 Trans. Mackerel		
18 Large Dem. Piscivores		
19 Small Dem.Piscivores		
20 Large Large Demersals		
21 Small Large Demersals		
22 Small Demersals		
23 Capelin		
24 Sand lance		
25 Trans. Pelagics		
26 Small Pelagics		
27 Small Mesopelagics		
28 Squid		
29 Large Crabs		
30 Small Crabs		
31 Shrimp		0.134
32 Echinoderms		0.005
33 Polychaetes		0
34 Bivalve Mollusc		0
35 OBI	0.039	0.000
36 Large Zooplankton	0.209	0.723
37 Small zooplankton	0.712	0.097
38 Phytoplankton		
39 Detritus	0.040	0.040
Total	1.000	1.000

Diet 1 is from George's Bank, a weighted average of data for the 1970s and 1980s. There were not data for the 1990s.

Diet 2 is data collected from the eastern Scotian Shelf from 1999 to 2000. 4% detritus has been added to this diet in keeping with description in the literature.

Diet 1 was used to represent sand lance diet in the 1980-1985 time period and diet 2 in the 1995-2000 time period.

Table 25. Transient Pelagics Diet for 1980-1985 and 1995-2000.

					1980-1985
	Diet	1	2	3	4
	Ecopath Group				
3	Seabirds	0.021	0	0.011	0.011
4	Large Cod	0	0	0.000	0.000
5	Small Cod	0	0	0.000	0.000
6	Large Silver Hake	0.113	0.021	0.067	0.071
7	Small Silver Hake	0	0.023	0.012	0.012
8	Haddock	0	0	0.000	0.000
9	American Plaice	0	0	0.000	0.000
10	Large Halibut	0	0	0.000	0.000
11	Small Halibut	0	0	0.000	0.000
12	Flounders	0.079	0	0.040	0.042
13	Skates	0.014	0	0.007	0.007
14	Dogfish	0.057	0	0.028	0.030
15	Redfish	0	0.115	0.058	0.061
16	Pollock	0	0	0.000	0.000
17	Trans. Mackerel	0.091	0.198	0.144	0.152
18	Large Dem. Piscivores	0.028	0	0.014	0.015
19	Small Dem.Piscivores	0	0	0.000	0.000
20	Large Large Demersals	0.113	0	0.057	0.060
21	Small Large Demersals	0	0	0.000	0.000
22	Small Demersals	0	0	0.000	0.000
23	Capelin	0.079	0	0.040	0.010
24	Sand lance	0.003	0	0.001	0.001
25	Trans. Pelagics	0.026	0	0.013	0.013
26	Small Pelagics	0	0.155	0.078	0.082
27	Small Mesopelagics	0	0.056	0.028	0.030
28	Squid	0.345	0.432	0.388	0.388
29	Large Crabs	0.010	0	0.005	0.005
30	Small Crabs	0	0	0.000	0.000
31	Shrimp	0	0	0.000	0.000
32	Echinoderms	0	0	0.000	0.000
33	Polychaetes	0	0	0.000	0.000
34	Bivalve Mollusc	0	0	0.000	0.000
35	OBI	0.010	0	0.005	0.005
36	Large Zooplankton	0.010	0	0.005	0.005
37	Small zooplankton	0	0	0.000	0.000
38	Phytoplankton	0	0	0.000	0.000
39	Detritus	0	0	0.000	0.000
	Total	1.000	1.000	1.000	1.000

Diet 1. Blue shark diet data, adapted from data in Kohler and Stillwell (1981). Data were collected from George's Bank, 1972-1980, from March to October. 863 stomachs were collected, 444 were empty.

Diet 2. Swordfish diet data reported in Laurinolli et al (2003). These data were collected from Georges Bank, the Scotian Shelf and the Grand Banks in 1980 from August to September during industry long-line surveys.

Diet 3. Diet for 1995-2000, Average of diets 1 and 2.

Diet 4. Diet for 1980-1985, which excludes capelin since capelin abundance was minimal in this time period. Capelin is reduced to 0.01, and the difference distributed over the other fish groups.

Table 26. Small Pelagics Diet for 1980-1985 and 1995-2000.

	1	2	3
7 Small Silver Hake	0.028		
8 Haddock	0		
9 American Plaice	0		
10 Large Halibut	0		
11 Small Halibut	0		
12 Flounders	0		
13 Skates	0		
14 Dogfish	0		
15 Redfish	0		
16 Pollock	0		
17 Trans. Mackerel	0		
18 Large Dem. Piscivores	0		
19 Small Dem.Piscivores			
20 Large Large Demersals	0		
21 SmallLarge Demersals			
22 Small Demersals	0.002		
23 Capelin	0		
24 Sand lance	0		
25 Trans. Pelagics	0		
26 Small Pelagics	0		
27 Small Mesopelagics	0		
28 Squid	0		
29 Large Crabs	0		
30 Small Crabs	0		
31 Shrimp	0.046		0.046
32 Echinoderms	0		0.000
33 Polychaetes	0		0.000
34 Bivalve Mollusc	0		0.000
35 OBI	0.156	0.1	0.100
36 Large Zooplankton	0.647	0.513	0.513
37 Small zooplankton	0.121	0.387	0.341
38 Phytoplankton	0		0.000
39 Detritus	0		0.000
			1

Diet 1 is from George's Bank, 1990-1998, J. Links, NMFS, Pers. Comm.

Diet 2 is from Table 4 of Messieh et al 1979, as described in Bundy et al 2001, Appendix 2, Table 17.

Diet 3 is diet 2, with shrimp added, as in diet 1. The difference is subtracted from the large zooplankton component of the diet.

Diet 3 was used for both model time periods.

Table 27. The diet of mesopelagics for 1980-1985 and 1995-2000.

	1	2
23 Capelin	0.01	0.001
24 Sand lance		
25 Trans. Pelagics		
26 Small Pelagics		
27 Small Mesopelagics	0.05	0.05
28 Squid	0.04	0.04
29 Large Crabs		
30 Small Crabs		
31 Shrimp		
32 Echinoderms		
33 Polychaetes		
34 Bivalve Mollusc		
35 OBI		
36 LZP	0.45	0.459
37 SZP	0.45	0.45
38 Phytoplankton		
39 Detritus		
	1	1

Diet 1. Mesopelagic diet from Newfoundland (Lilly 2002).
Diet 2. Diet 1 adapted for the eastern Scotian Shelf in 1980-1985. The amount of capelin has been reduced from 1% to 0.1% and the difference added to large zooplankton.

Table 28. The diet of short-finned squid for 1980-1985 and 1995-2000.

	1	2	3	4	5	6	7	8	9	10
5 Small Cod	0.05	0.00	1.34	3.65	0.05	0.37	2.72	0.14	1.38	0.014
6 Large Silver Hake										
7 Small Silver Hake	0.23	0.00	6.69	18.23	0.23	17.85	13.62	0.69	9.55	0.096
8 Haddock	0.05	0.00	1.34	3.65	0.05	0.37	2.72	0.14	1.38	0.014
9 American Plaice										
10 Large Halibut										
11 Small Halibut										
12 Flounders										
13 Skates										
14 Dogfish										
15 Redfish										
16 Pollock	0.05	0.00	1.34	3.65	0.05	0.37	2.72	0.14	1.38	0.014
17 Trans. Mackerel										
18 Large Dem. Piscivores										
19 Small Dem.Piscivores	0.05	0.00	1.34	3.65	0.05	0.37	2.72	0.14	1.38	0.014
20 Large Large Demersals										
21 SmallLarge Demersals	0.20	0.00	5.80	15.80	0.20	1.60	11.80	0.60	5.97	0.060
22 Small Demersals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
23 Capelin										
24 Sand lance										
25 Trans. Pelagics										
26 Small Pelagics										
27 Small Mesopelagics	0.38	0.00	11.15	39.38	0.38	7.08	22.69	3.15	13.97	0.140
28 Squid	0.00	0.00	24.00	2.00	51.00	36.00	26.00	12.00	25.17	0.252
29 Large Crabs										
30 Small Crabs	0.00	0.00	0.00	0.00	0.00	0.00	14.00	0.00	2.33	0.023
31 Shrimp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
32 Echinoderms										
33 Polychaetes										
34 Bivalve Mollusc										
35 OBI										
36 Large Zooplankton	0.00	0.70	39.50	7.00	33.60	33.90	1.00	70.10	30.85	0.309
37 Small zooplankton	0.00	0.30	7.50	3.00	14.40	2.10	0.00	12.90	6.65	0.067
38 Phytoplankton										
39 Detritus	0.00	0.00								
FISH			29.00	79.00	1.00	8.00	59.00	3.00		
UNID Crust.				10.00	6.00	6.00		43.00		
Decapods			25.00		42.00	1.00				

Diet 1 - Fish components of squid diets listed in Armatunga (1983, Table 3). The terms abundance, present and common used by Armatunga are quantified.

Diet 2 - Crustacean components of squid diets listed in Armatunga (1983, Table 3). The terms abundance, present and common used by Armatunga are quantified.

Diet 3 - Diet of squid 8-15 cm in depth 42-70 m (Vinogradov and Noskov 1979). 29% of the diet were unidentified fish – these were distributed based on the proportions in diet 1. 25 % were unidentified decapods – these were distributed based on the proportions in diet 2.

Diet 4 - Diet of squid 16-30 cm in depth 42-70 m (Vinogradov and Noskov 1979). 79% of the diet were unidentified fish – these were distributed based on the proportions in diet 1. 10 % were unidentified crustaceans – these were distributed based on the proportions in diet 2.

Diet 5 - Diet of squid 8 - 15 cm in depth 71 – 150 cm (Vinogradov and Noskov 1979). 1 % of the diet were unidentified fish – these were distributed based on the proportions in diet 1. 42 % were unidentified decapods, and 6 % unidentified crustaceans – these were distributed based on the proportions in diet 2.

Diet 6 - Diet of squid 16-30 cm in depth 71 – 150 m (Vinogradov and Noskov 1979). 8 % of the diet were unidentified fish – these were distributed based on the proportions in diet 1. 1 % were

unidentified decapods, and 6 % unidentified crustaceans – these were distributed based on the proportions in diet 2.
Diet 7 - Diet of squid 8-15 cm in depth 151 - 365 m (Vinogradov and Noskov 1979). 59% of the diet were unidentified fish – these were distributed based on the proportions in diet 1.
Diet 8 - Diet of squid 8-15 cm in depth 42-70 m (Vinogradov and Noskov 1979). 3 % of the diet were unidentified fish – these were distributed based on the proportions in diet 1. 43 % were unidentified crustaceans – these were distributed based on the proportions in diet 2.
Diet 9 – A simple average of diets 3-8.
Diet 10. – Diet 9 expressed as proportions.

The same diet was used for the 1980-1985 and 1995-2000 time period. This is a very approximate diet, using two different data sources and has a high degree of uncertainty.

Table 29. Large and Small Crab Diets.

	1	2	3	4
29 Large Crabs				
30 Small Crabs	0.028	0.000	0.025	0.000
31 Shrimp	0.095	0.000	0.085	0.000
32 Echinoderms	0.270	0.170	0.243	0.153
33 Polychaetes	0.120	0.160	0.108	0.144
34 Molluscs	0.008	0.013	0.007	0.012
35 Other benthic invertebrates	0.316	0.483	0.284	0.435
36 Large Zooplankton	0.164	0.174	0.148	0.157
37 Small Zooplankton	0	0	0	0
38 Phytoplankton	0	0	0	0
39 Detritus	0	0	0.1	0.1
	1.000	1.000	1.000	1.000

Diet 1. Large crab diet derived from Tables 2 and 3 in Brêthes et al 1984 from samples taken from depths greater than 110 m since larger crabs tend to be found in deeper water.

Diet 2. Small crab diet derived from Tables 2 and 3 in Brêthes et al 1984 from samples taken from depths between 90 and 110 m since smaller crabs tend to be found in shallower water. It was assumed that small crabs do not eat small crabs or shrimp.

Diet 3 and 4. Diets 1 and 2 respectively with 10 % detritus added to the diet (consistent with other diet studies of snow crabs), and the other diet components reduced by 10%.

Table A. 30. Shrimp diet for 1980-1985 and 1995-2000.

	1
33 Polychaetes	0.015
34 Bivalve Mollusc	
35 OBI	0.015
36 LZP	0.12
37 SZP	0.24
38 Phytoplankton	0.085
39 Detritus	0.525
40 Import	
41 Sum	1

Diet 1. Diet taken from diet used for Newfoundland model presented in Bundy et al (2000).

APPENDIX 3

13 March 2001

Density Estimates of Cetaceans and Turtles in Two Strata on the Scotian Shelf
Version 2

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INTRODUCTION

In response to a request from Dr. Alida Bundy of the Marine Fish Division, Bedford Institute of Oceanography, Darmouth, Nova Scotia, Canada, I have estimated the density of cetaceans and turtles that were detected within two strata she was interest in. The Eastern Scotian Shelf stratum (Table 1) was most completely covered by the aerial portion of the Northeast Fisheries Science Center's (NEFSC) 1995 summer line-transect abundance survey (Figure 1). The Western Scotian Shelf stratum (Table 1) was most completely covered by the aerial portion of the NEFSC 1998 summer line-transect abundance survey (Figure 2). The aerial portions of both of these surveys were conducted by the NOAA Twin Otter with three observers and a recorder. Two observers were viewing through side bubble windows and the third observer was viewing through a center belly window. More details are in Palka *et al.* (in review) and Palka (2000).

METHODS

Density and its coefficient of variation (CV) were estimated using standard methods (Palka 2000; Palka *et al.*, in review). The density within stratum *i*, for species *j*, D_{ij}, was estimated using:

$$D_{ij} = \frac{n_{ij} \cdot E(s_{ij})}{2 \cdot L_i \cdot esw_j \cdot g(0)_j} \qquad (1)$$

where n_{ij} = number of detected groups of species *j* within stratum *i*,
$E(s_{ij})$ = expected size of groups of species *j* within stratum *i*,
L_i = length of track line within stratum *i*,
esw_j = effective strip width for species *j*,
$g(0)_j$ = probability of detecting a group of species *j* on the track line.

The lengths of track line surveyed in the Eastern and Western Scotian strata were 2054.1 and 2090.7 km, respectively.

The effective strip width (esw) was estimated from a histogram of perpendicular distances that modeled the detection function using the computer program DISTANCE (Buckland *et al.* 1993). Potential models included the uniform with cosine adjustments, half-normal with hermite adjustments, and hazard-rate with cosine adjustments. Model selection was based on minimum Akaike Information criterion (AIC). The esw for a species was estimated from data from all the sightings of the species that were seen during the respective year from the airplane, except in two cases. Because there were too few large whales and common dolphins detected within a year to make a species-specific estimate of the esw, groups of animals with similar sighting characteristics were pooled. Within a year, humpback whale (*Megaptera novaeangliae*), fin whale (*Balaenoptera physalus*), and sperm whale (*Physeter macracephalus*) were pooled and common dolphin (*Delphinus delphis*) and bottlenose dolphin (*Tursiops truncatus*) were pooled.

The expected group size was the arithmetic mean of the observed groups in a stratum unless there was an indication of group size bias. Bias occurs because at far distances it is more likely to see large groups than small groups. In these cases, the predicted group size on the track line is the expected group size, where species-specific data from the entire survey were used. The expected group size on the track line is predicted from the regression of g(y) versus log(group size), where g(y) is the probability of detecting a group at distance y from the track line (Buckland *et al.* 1993). The bias corrected group size was estimated using the computer program DISTANCE.

It was assumed that all animals, except harbor porpoise (*Phocoena phocoena*), were detected on the track line. That is, *g(0)* was assumed to be one for all species except harbor porpoise, where *g(0)* was estimated to be 0.24 (CV=0.86) (Palka 1996). The *g(0)* for harbor porpoises was estimated from data collected from a ship and airplane experiment conducted in 1995. The parameter *g(0)* was not estimated for most species because there was no independent team experiment, as in the harbor porpoise ship-airplane experiment. The consequence of assuming *g(0)*=1 is the density estimate is negatively biased.

The CV of density was estimated using:

$$CV(D_{ij}) = \sqrt{CV^2(n/L) + CV^2(E(s)) + CV^2(esw) + CV^2(g(0))} \qquad (2)$$

where

$$CV^2\left(\frac{n}{L}\right) = \frac{\left(\sum_{i=1}^{k}\frac{l_i}{L}\left(\frac{n_i}{l_i}-\frac{n}{L}\right)\right)\Big/_{k-1}}{(n/L)^2} \,. \qquad (3)$$

k is the number of transects within stratum, *L* is the sum of l_i, and *n* is the sum of n_i, and

$$CV^2(\bar{s}) = \frac{\sum_{i=1}^{n}\left(s_i - \bar{s}\right)^2 \Big/ n\cdot(n-1)}{\left(\bar{s}\right)^2} \qquad (4)$$

The CV(E(s)) when the regression method was used is estimated from the regression equation (Buckland *et al.* 1993).

The CV(*g(0)*) for harbor porpoises was estimated from the data collected during the 1995 ship-airplane experiment (Palka 1996).

RESULTS

During the 1995 NEFSC aerial survey, 54 groups of cetaceans were detected in the Eastern Scotian stratum (Figure 3; Table 2). This included 2 groups of bottlenose dolphin, 1 common dolphin, 22 white-sided dolphin (*Lagenorhynchus acutus*), 6 pilot whale (*Globicephala* spp.), 4 minke whale (*Balaenoptera acutorostrata*), 9 fin whale, 9 humpback whale, and 1 sperm whale group. The average group size ranged from 1 to 40 animals per group. The bias corrected group size ranged from 1 to 14.5 animals per group (Table 2).

During the 1998 NEFSC aerial survey, 148 groups of cetaceans and turtles were detected in the Western Scotian stratum (Figure 4; Table 3). This included 26 groups of common dolphin, 10 white-sided dolphin, 65 harbor porpoise, 7 pilot whale, 6 minke whale, 15 fin whale, 8 humpback whale, 3 sperm whale, 6 right whale, and 2 leatherback turtle (*Demochelys coriacae*) group. The average group size ranged from 1 to 23.5 animals per group. The bias corrected group size ranged from 1 to 16.6 animals per group (Table 3).

Density estimates of cetaceans in the Eastern Scotian stratum range from 0 for harbor porpoise and leatherback turtle to 0.2588 animals/km^2 (CV=0.54) for white-sided dolphin (Table 4). Density estimates of cetaceans in the Western Scotian stratum range from 0 for bottlenose dolphin to 1.0975 animals/km^2 (CV=0.92) for harbor porpoise (Table 4).

DISCUSSION

Except for harbor porpoises, all of the density estimates are negatively biased, because *g(0)* was not estimated and dive time corrections were not included. Especially for dolphins, the assumption of *g(0)*=1 is not valid because they are small and difficult to detect. However, without using an independent team or another sighting procedure, it is not possible to determine the degree of bias. Especially for the large whales, the effect of no dive time corrections could potentially be large, because many of these species spend a long time under water, where there no chance of the aerial observers detecting them.

The CVs of the density estimates for all species are large. The largest component of the overal CV is the variability in the encounter rate (n/L). This is mainly due to the fact that the strata ar small, the detection rates of the animals are low, and the animals are naturally clustered. The spatial heterogeneity phenomenon is common for cetaceans. The CV's could be reduced if m survey effort was conducted in the strata and the strata were covered more completely.

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Table 1. Latitude and longitude locations of corners of the Eastern and Western Scotian strata.

Eastern Scotian Stratum		Western Scotian Stratum	
63° 20'	44° 10'	65° 54.5'	45° 11'
59° 00'	45° 40'	65° 40'	44° 46'
57° 40'	45° 40'	66° 25'	44° 16.5'
56° 32'	44° 32'	66° 00'	43° 17.25'
63° 20'	42° 27'	65° 12.75'	43° 25.25'
63° 20'	44° 10'	63° 20'	44° 20'
		63° 20'	42° 47'
		65° 39'	42° 00'
		66° 30'	42° 23'
		67° 29'	42° 30'
		67° 40'	42° 40.5'
		67° 40'	44° 20.35'
		66° 40.15'	44° 50.6'

Table 2. For species detected within the Eastern Scotian stratum, the number of groups (n), effective strip width (esw) in meters, arithmetic group size (Avg S), and the E(s) that was used in the density estimate. In addition, the CV's for these parameters are provided.

Species	n	CV(n/l)	esw	CV(esw)	Avg S	E(s)	CV(E(s))
bottlenose dolphin	2	0.66	131	0.25	40.0	4.2	0.27
common dolphin	1	0.95	131	0.25	7.0	7.0	0.00
white-sided dolphin	22	0.47	300	0.15	43.3	14.5	0.23
pilot whale	6	0.50	217	0.14	10.2	4.8	0.24
minke whale	4	0.42	415	0.20	1.0	1.0	0.00
fin whale	9	0.31	429	0.17	2.4	1.4	0.18
humpback whale	9	0.69	429	0.17	1.4	1.4	0.20
sperm whale	1	1.05	429	0.17	1.0	1.0	0.00

Table 3. For species detected within the Western Scotian stratum, the number of groups (n), effective strip width (esw) in meters, arithmetic group size (Avg S), and the E(s) that was used in the density estimate. In addition, the CV's for these parameters are provided.

Species	n	CV(n/l)	esw	CV(esw)	Avg S	E(s)	CV(E(s))
common dolphin	26	0.67	450	0.12	23.5	16.6	0.20
white-sided dolphin	10	0.33	429	0.11	17.5	15.4	0.32
harbor porpoise	65	0.25	237	0.16	4.0	4.0	0.13
pilot whale	7	0.61	406	0.32	8.7	8.7	0.25
minke whale	6	0.48	553	0.21	1.0	1.0	0.00
fin whale	15	0.42	387	0.05	1.5	1.5	0.23
humpback whale	8	0.51	387	0.05	1.6	1.6	0.23
sperm whale	3	0.68	387	0.05	2.0	2.0	0.50
right whale	6	0.75	387	0.05	1.7	1.7	0.30
leatherback turtle	2	0.52	282	0.05	1.0	1.0	0.00

Table 4. Estimates of density (animals/km^2) and it's CV for each species detected in the Eastern and Western Scotian strata.

Species	Eastern Scotian stratum		Western Scotian Stratum	
	density	CV	density	CV
bottlenose dolphin	0.0156	0.76	0.0000	0.00
common dolphin	0.0130	0.98	0.2294	0.71
white-sided dolphin	0.2588	0.54	0.0856	0.47
harbor porpoise[1]	0.0000	0.00	1.0975	0.92
pilot whale	0.0323	0.57	0.0359	0.73
minke whale	0.0023	0.47	0.0026	0.53
fin whale	0.0071	0.40	0.0142	0.48
humpback whale	0.0074	0.74	0.0080	0.56
sperm whale	0.0006	1.06	0.0037	0.84
right whale	0.0000	0.00	0.0062	0.81
leatherback turtle	0.0000	0.00	0.0017	0.52

[1] Density of harbor porpoise includes an estimate of $g(0)$=0.24 (CV=0.86). Density estimates of other species assumes $g(0)$=1.

Figure 1. Eastern Scotian Stratum (red dashed outline) overlaying the NEFSC strata (thick black lines) that were surveyed during the summer of 1998. In addition, the track lines (thin black lines), Western Scotian Stratum (blue dotted line), 100m and 2000m depth contours are displayed.

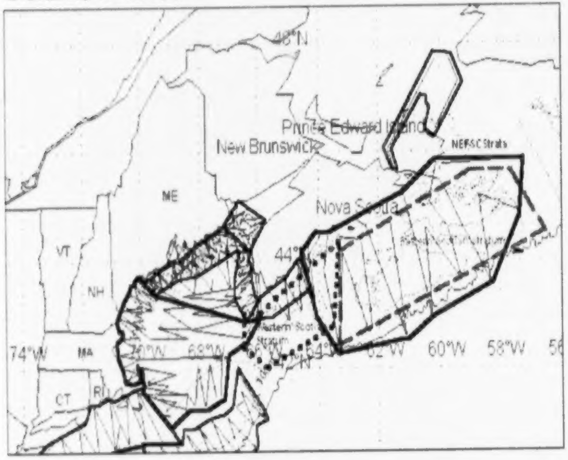

Prince Edward Island
New Brunswick
NEFSC Strata
ME
Nova Scotia
Eastern Scotian Stratum
VT
NH
44°N
Western Scotian Stratum
74°W
MA
70°W
68°W
64°W
62°W
60°W
58°W
CT
RI

Figure 2. Western Scotian Stratum (blue dotted line) overlaying the NEFSC strata (thick black lines) that were surveyed during the summer of 1998. In addition, the track lines (thin black lines), Eastern Scotian Stratum (red dashed line), 100m and 2000m depth contours are displayed. Highlighted track line was included as part of the Western Scotian stratum.

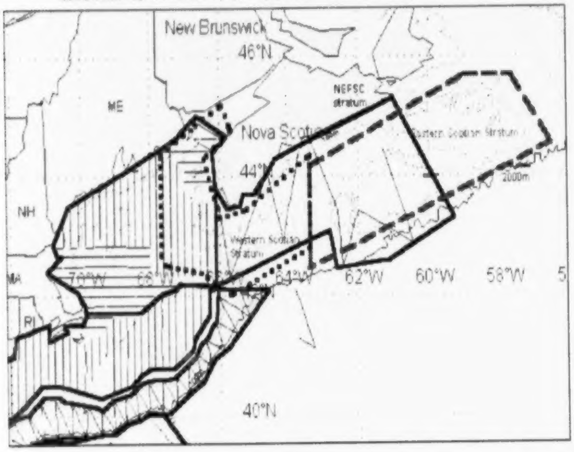

New Brunswick
46°N
NEFSC Stratum
ME
Nova Scotia
Eastern Scotian Stratum
44°N
2000m
NH
Western Scotian Stratum
MA
70°W
66°W
64°W
62°W
60°W
58°W
RI
40°N

Figure 3. Cetaceans detected in the Eastern Scotian Stratum (red outline) over laying the NEFSC E. Scotian stratum (thick black line) that was surveyed by airplane during the summer of 1995. In addition, the track lines (thin black lines) and 100m and 2000m contours are displayed.

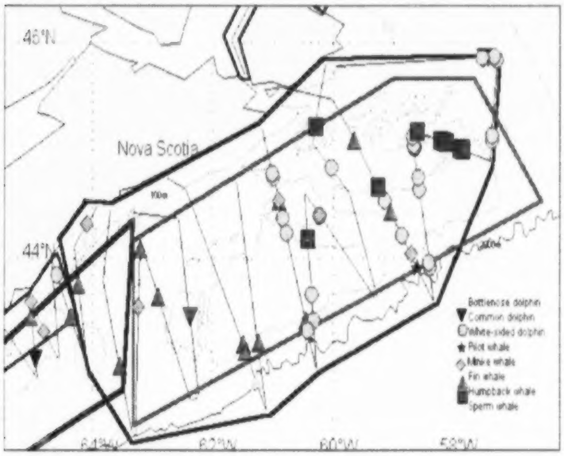
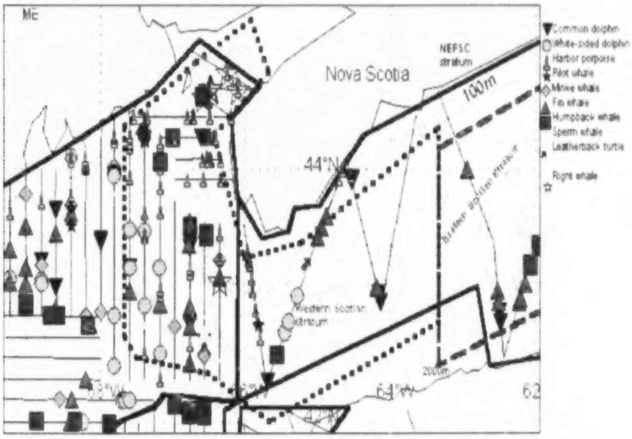

45°N
Nova Scotia
100m
44°N
2000m
Bottlenose dolphin
Common dolphin
White-sided dolphin
Pilot whale
Minke whale
Fin whale
Humpback whale
Sperm whale
64°W
62°W
60°W
58°W

Figure 4. Cetaceans detected in the Western Scotian Stratum (blue dotted line) overlaying the NEFSC strata (thick black lines) that were surveyed during the summer of 1998. In addition, the track lines (thin black lines), Eastern Scotian Stratum (red dashed line), 100m and 2000m depth contours are displayed.


ME
Nova Scotia
NEFSC stratum
100m
44°N
Eastern Scotian stratum
Western scotian stratum
2000m
66°W
64°W
62
Common dolphin
White-sided dolphin
Harbor porpoise
Pilot whale
Minke whale
Fin whale
Humpback whale
Sperm whale
Leatherback turtle
Right whale

APPENDIX 4 - METHODOLOGY FOR ESTIMATING BIOMASS OF COPEPODS ON THE SCOTIAN SHELF (ERICA HEAD AND LES HARRIS, BIO).

Sampling:
Zooplankton were collected from the 0-100 m or 0-bottom (whichever was shallower) by vertical ring net tows using a 200 μm mesh net. The net was fixed vertically on the wire, such that it only collected zooplankton when being towed upwards. Samples were preserved in 5% formalin prior to analysis back in the laboratory. For calculations of biomass, values from stations with depths < 200 m of the Browns Bank (Stns. 1-4) and Roseway (Stns. 1-4) Lines were averaged to give biomass concentrations for the western Scotian Shelf (Fig. 1). Values from stations with depths < 200 m of the Halifax (Stns. 1-5) and Louisbourg Lines (Stns. 1-6) were averaged to give biomass concentrations for the eastern Scotian Shelf. In general, in April and October station coverage was complete. In other months except May 2001 and June 1996, biomass in the east was estimated from stations of the Halifax line only.

Analysis:
Groups of copepods were picked out of the preserved samples and dried at 60°C for 1-3 days. The groups were: individual stages of *Calanus* spp. (*C. finmarchicus*, *C. hyperboreus*, *C. glacialis*); all stages combined of other common genera (*e.g. Oithona*, *Metridia*, *Pseudocalanus*); and, aliquots of other "large" and "small" copepods. The total dry weight biomass for each sample was calculated by summing the dry weights of these groups according to their abundance in the sample. Areal concentrations were calculated by assuming that the net fished a volume of water equal to that of the cylinder its path described and by multiplying by the tow depth. Wet weight biomass was calculated by multiplying dry weight biomass by a factor of ten to allow for loss of water and volatile or soluble material during preservation and drying.

Fig. 1. Zooplankton sampling stations on the Scotian Shelf. BBL= Browns Bank Line, RL= Roseway Line, HL= Halifax Line, GUL= Gully, LL= Louisbourg Line, CSL= Cabot Strait Line